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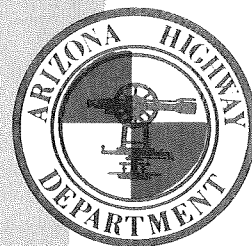
ARIZONA HIGHWAY DEPARTMENT
RESEARCH DIVISION

STABILIZATION OF CHINLE CLAY BY ELECTRO-OSMOSIS AND BASE EXCHANGE OF IONS

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FINAL REPORT

Prepared for:
ARIZONA HIGHWAY DEPARTMENT
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| 16. Abstract Over the period of the past year, extensive field and laboratory testing has been conducted on Chinle Clay. The laboratory testing has consisted of electro-osmotic testing with various wetting agents to determine the most effective wetting agent. This has encompassed tests from small 6-inch tube samples up to and including a 5 cubic foot model. The field portion consisted of two small-scale tests. The first investigated the effects of various wetting agents and the geometric arrangements of electrodes. The second was performed on an existing abandoned road section, in order to determine the optimum method of distribution of chemical solution. Based on these tests, it has been concluded that the post hole method and the commercial wetting agent C-61 are the most effective means of treating the Chinle Clay when electro-osmotic processes are used for stabilization. | | | | | |
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PREFACE

The data presented in this report represents over a year's work conducted by both Arizona State University and The Arizona Highway Department. This work entails the development of a field procedure for the stabilization of Chinle Clay using electro-osmosis.

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Chapter 1

INTRODUCTION

SPONSORSHIP

This report is based on work performed by the Engineering Research Center, Arizona State University, Tempe, Arizona, under contract with the Arizona State Highway Department to investigate "Stabilization of Chinle Clay by Electro-osmotic Treatment." Funds for the project were provided by the Arizona State Highway Department.

NATURE OF PROBLEM

A vast extent of Northern Arizona is covered by an expansive Montmorillonite clay. This formation is called Chinle clay and has approximately 6,000 square miles of surface exposure as shown in Figure 1. Throughout this area, the clay has many colors ranging from light gray to dark purple. Although one will find this material in a wide range of colors, the swelling characteristics are quite similar. The natural expansive characteristics of the Chinle clay are large, and in the past they have caused excessive swelling and heaving in highway subgrades. This volumetric change has caused damage or failure to the pavement structure of existing highways.

Recognizing this condition, the Arizona Highway Department has made every attempt to control the swelling by preventing the drying of the soil during the construction program. This requires additional work and construction materials, and to date the method has not been completely adequate.

MAP OF ARIZONA SHOWING MAJOR CHINLE OUTCROPS

2

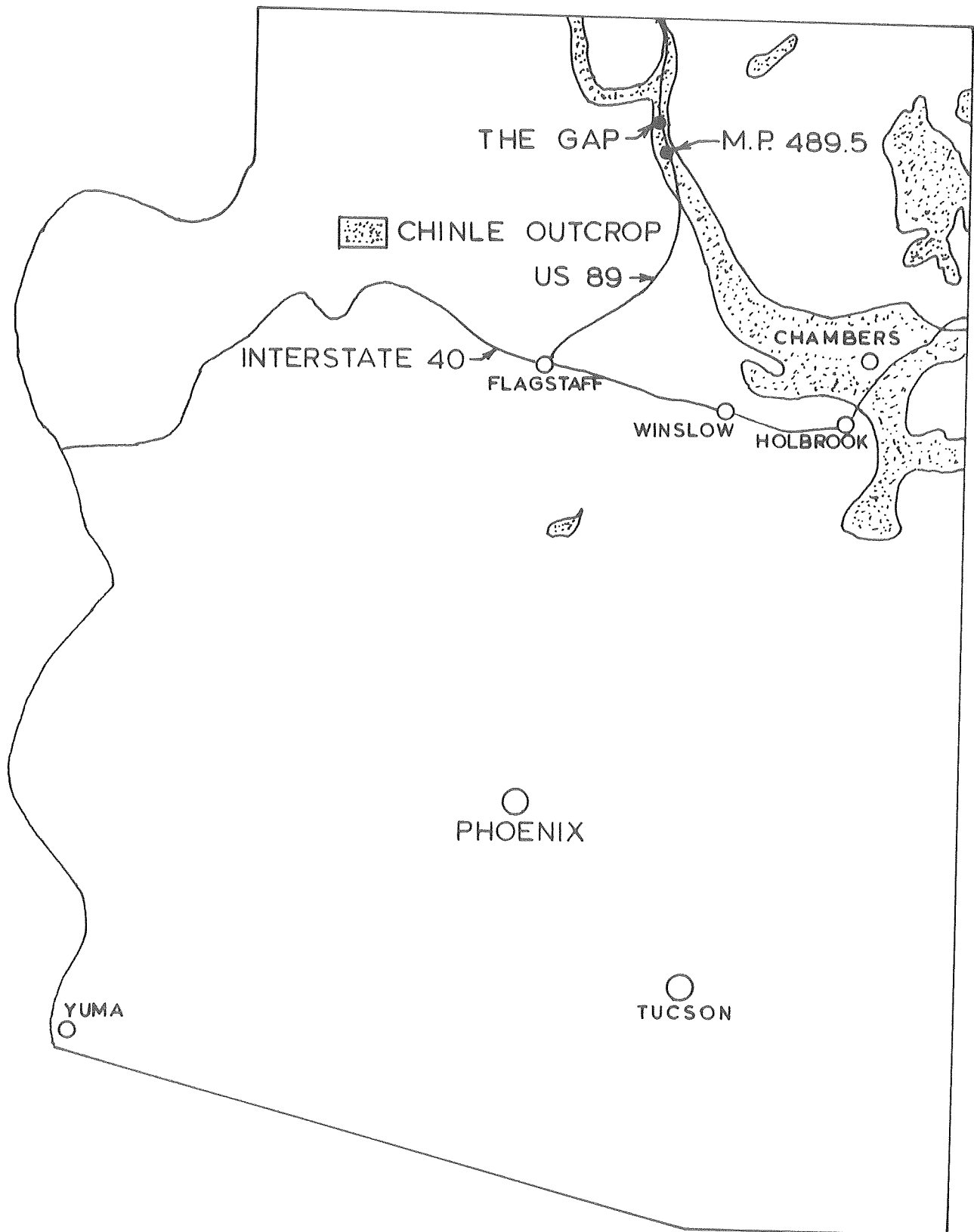


Figure 1

APPROACH TO THE PROBLEM

There are several alternatives available for stabilizing expansive clays. Possibilities are: (1) insulating the clay from soil moisture with some waterproofing material; however, this method is only applicable to new construction and could not be used on the vast majority of the existing roadways that are experiencing volumetric heaving, (2) cementing the individual clay structure by flooding the subgrade prior to construction, and (4) using electro-osmotic treatment and base exchange of ions in conjunction with a wetting agent to reduce the swelling characteristics of the material.

Of the four possible solutions stated above, the Highway Department decided to attempt to solve the problem by the use of electro-osmotic principle and base exchange of ions. There are several advantages to this method of stabilization:

1. The stabilization of existing highways can be accomplished without the necessity of removing and reworking the in-place material.
2. Once the treatment and stabilization of expansive clays had been accomplished, the results would be irreversible over the engineering life of the highway.
3. After treatment and stabilization of the expansive clay, radical changes in moisture content of the subgrade would not cause excessive changes in volume.

OBJECT OF RESEARCH

The object of this research was to determine the most effective commercial wetting agent used in conjunction with electro-osmosis and potassium chloride in an effort to reduce the swelling characteristics

of the Chinle Clay. Based on four years of previous research, it has been determined that although various chemicals will reduce the expansive pressure of the chinle clay, potassium chloride is by far the most effective and efficient. Employing this treatment, it is expected that existing highways can be effectively stabilized.

SCOPE OF REPORT

This report on the "Stabilization of Chinle Clay by Electro-Osmosis and Base Exchange of Ions" is presented in seven chapters. These chapters explain in detail the various areas of laboratory and field experimentation conducted since August 1, 1971. Chapter 2 contains the site location and gives a brief discussion of the geology of the site and the existing conditions. Chapter 3 contains a complete discussion of all laboratory tests performed on the soil obtained from the test site. Chapter 4 goes into the details and investigations performed during the first field test conducted in November of 1971. Chapter 5 covers the laboratory studies involved in the large-scale model tests on the untreated soil from the selected site. Chapter 6 covers the design, installation, and sampling of the electro-osmotic field test in May, 1972. Chapter 7 is a summary with the conclusions and recommendations that have become apparent during the course of this research project.

Chapter 2

LOCATION AND GEOLOGY OF SITE

LOCATION

A typical site containing the expansive clay was selected near the vicinity of The Gap, Arizona, at milepost 489.5. This sampling location was selected because it was in an area that had experienced significant volumetric changes. At this site, approximately the top one foot was badly weathered. This material was stripped to expose the parent material. The weathered soil has the reticulated appearance typical of expansive clays. The unweathered material is quite hard, is fractured, and contains slickensides. About two cubic yards of disturbed parent material were obtained from the side hill cut at the site.

GEOLOGY OF SITE

For a complete discussion of the geology of the site, the reader is referred to "The Stabilization of Expansive Clay Soils by Chemical Additives," R. L. Sloane and G. L. Martin, Arizona Transportation and Traffic Institute, the University of Arizona, Tucson, 1964.

A brief summary of that report is as follows:

As reported by Kiersch (1)*, the claystones at this location are Upper Triassic in age and belong to the Petrified Forest Member of the Chinle Formation. The claystone deposit lies in the Upper Bentonitic Unit to distinguish it from a similar unit found in the lower part of the Chinle Formation. The upper bentonitic unit contains only claystones at the test section, although at somewhat lower elevations, in the vicinity of Willow

*Numbers in parentheses refer to entries in List of References.

Springs a few miles south of the test section, sandy claystones and siltstones predominate. The beds of the upper bentonitic unit dip moderately to the eastward across the valley (Tanner Wash) in a monocline. The top bed is comfortably overlain by soft to hard, red to brown, sandstones and mudstones of the Red-Brown Mudstone Unit.

According to Stokes (2), during the late Triassic when these beds were laid down, this part of the Colorado Plateau was at or very near to a shallow embayment of the warm seas from the southwest. Also at this time there was local volcanic activity. The claystones and mudstones were probably laid down in a warm shallow marine environment. The claystones are derived from alteration of volcanic ash; some probably deposited directly from the air into the water and others brought in by surface run-off as evidenced by the presence of detrital material in some of the beds. Alteration of the volcanic ash in such an environment is favorable to the formation of montmorillonoid and bentonitic clay minerals according to Grim (3).

Chapter 3

LABORATORY WORK

PURPOSE

The purpose of the laboratory work prior to the first field test was two-fold; first, to determine the optimum amount of potassium chloride needed to reduce the expansive pressure to an acceptable limit, and second, to find the wetting agent which would increase the rate of penetration of the KCl solution.

SITE SELECTION AND SAMPLING

The field work for this study began in August 1971, with the selection of a test site on US 89, 15 miles north of Cameron at milepost 489.5, see Figure 1. Approximately two cubic yards of soil were removed from a cut where swelling had been observed. The Highway Department transported the sample to Arizona State University where it was prepared for use in the laboratory studies.

SAMPLE PREPARATION

The sample was prepared in the following manner, see Figure 2. The soil was sieved through a #4 sieve. All material passing the #4 sieve was stockpiled. The material retained on the #4 sieve was taken to the Arizona Highway Department and crushed in their jaw crusher. The material was again sieved, and the minus #4 added to the stockpile. This crushing and sieving process was repeated until all the material

FLOW CHART FOR INITIAL SAMPLE PREPARATION

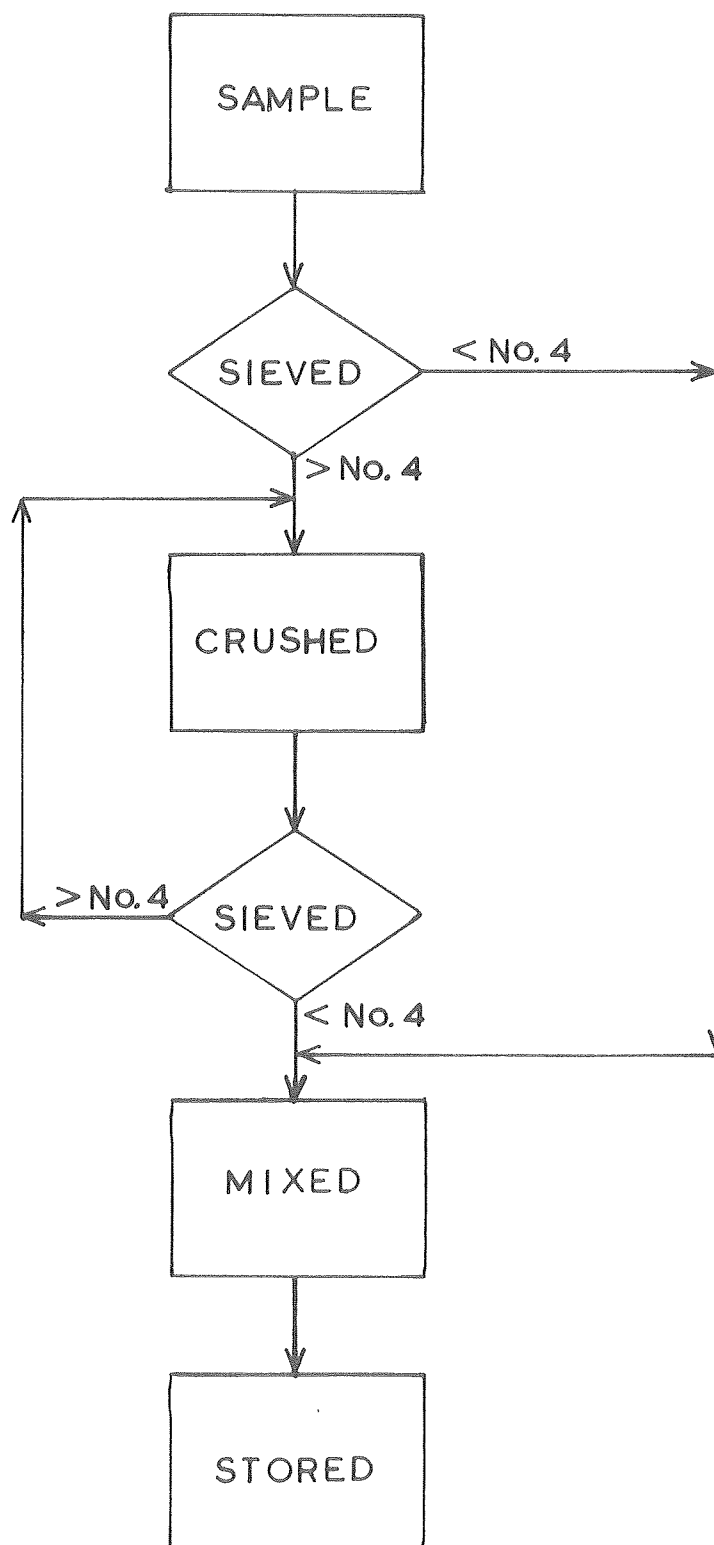


Figure 2

had passed the #4 sieve. The minus #4 material was then thoroughly mixed and stored in bins until needed for laboratory testing. In this manner, a homogeneous sample could be obtained for all future testing operations.

SOIL PROPERTIES OF UNTREATED MATERIAL

Tests were conducted to determine the index properties and a grain size distribution test was run. The sample had a liquid limit of 48, a plastic limit of 25, and a plastic index of 23. Ninety percent of the soil passed a #200 sieve. The soil classification is a CL material based on the unified soil classification system, and A-7-5[16] according to AASHTO. The specific gravity of the soil was 2.75. The expansive pressure of the soil was determined for material passing a #4 sieve and material passing a #40 sieve. The expansive pressure of the material passing the #4 sieve at 15 percent moisture and 105#/ft³ density was approximately 5,000 psf and the material passing the #40 sieve at 16 percent moisture and 105#/ft³ density was approximately 6,850 psf. (See Appendix A for explanation of expansiometer and procedure for running expansion tests.)

DETERMINATION OF OPTIMUM POTASSIUM CHLORIDE SOLUTION

In order to determine the optimum percentage of potassium chloride needed, various percentages by weight were mixed into the soil and expansion tests were performed on these samples. The samples were first crushed to minus #40 material. The KCl was then mixed into the soil with enough water to form a paste. The soil was then allowed to dry, and the water content measured. If the water content was between

14 and 18 percent the expansive pressure of the sample was measured. If not, the sample was either allowed to dry further or more water was added until the water content was within the above-mentioned limits. After the expansive pressure was run, the moisture content was again checked to insure that the sample had become at least 95 percent saturated and thus the maximum expansive pressure had been reached. If the sample failed to reach 95 percent saturation, the test was repeated. See Figure 3 for flow chart.

From these tests, it was determined that the optimum percent of potassium chloride using commercial grade KCl (62% K_2O min.) was between 4 and 5 percent by weight, see Figure 4.

DETERMINATION OF WETTING AGENT

In an attempt to increase the rate of penetration of the KCl solution into the clay, several wetting agents were tested. These included Aerosol O.T. (sodium dioctyl sulfosuccinate); Aerosol A.Y. (sodium diamyl sulfosuccinate); C-61 (ethanolated alkylgucineamine complex); propanol alcohol and Ultrawet. It was determined that the ideal wetting agent would meet the following five criteria: (1) increase the rate of penetration, (2) be compatible in solution with the potassium chloride, (3) in conjunction with the potassium chloride cause a decrease in expansive pressure, (4) require small amounts to be effective, and (5) be easy to mix in the field. None of the above wetting agents met all of these requirements.

The tests were performed by statically compacting the soil to 100 pcf dry density in a lucite tube 3.78 inches I.D. and 8 inches long.

FLOW CHART FOR EXPANSIVE PRESSURE VS. KCL

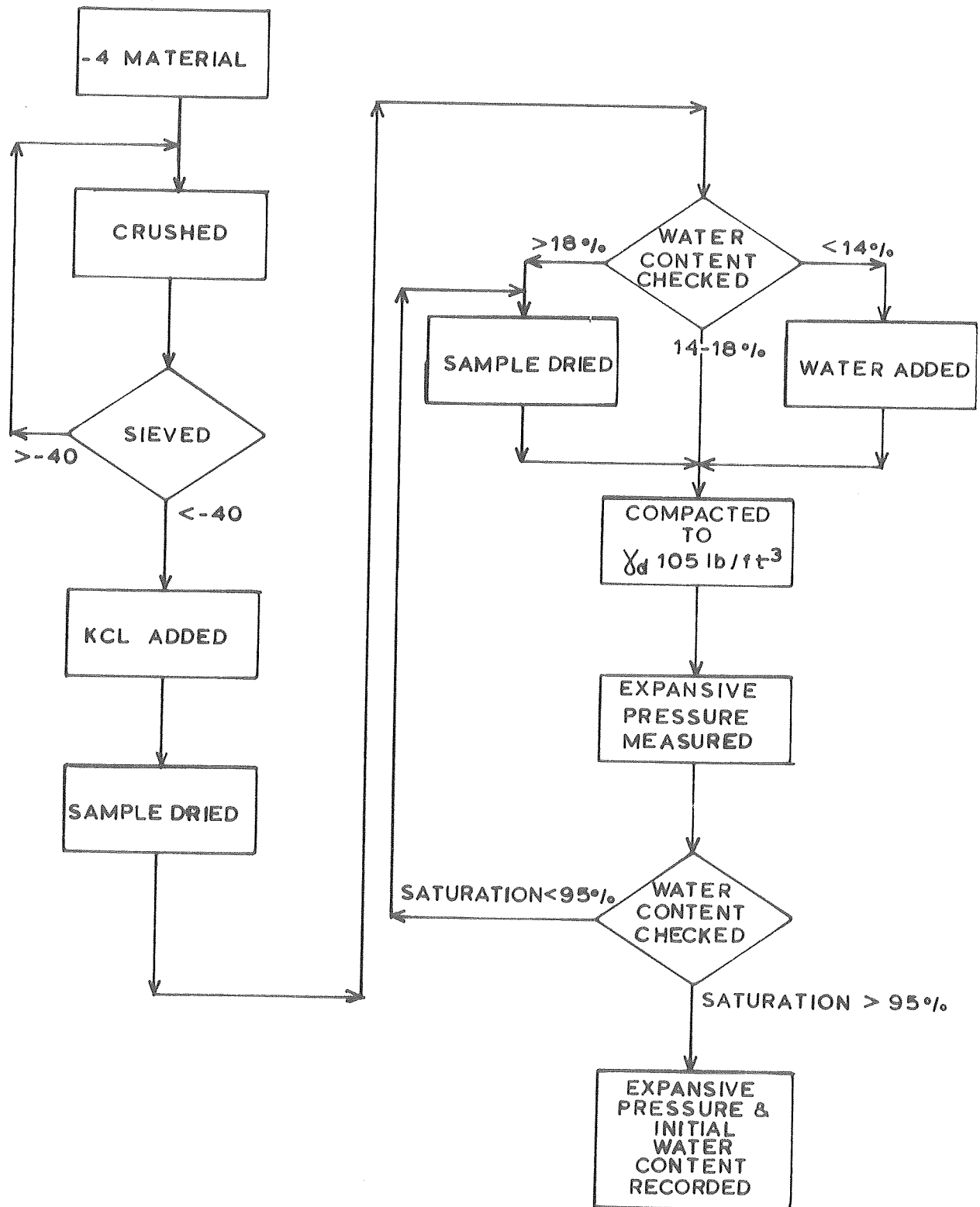


Figure 3

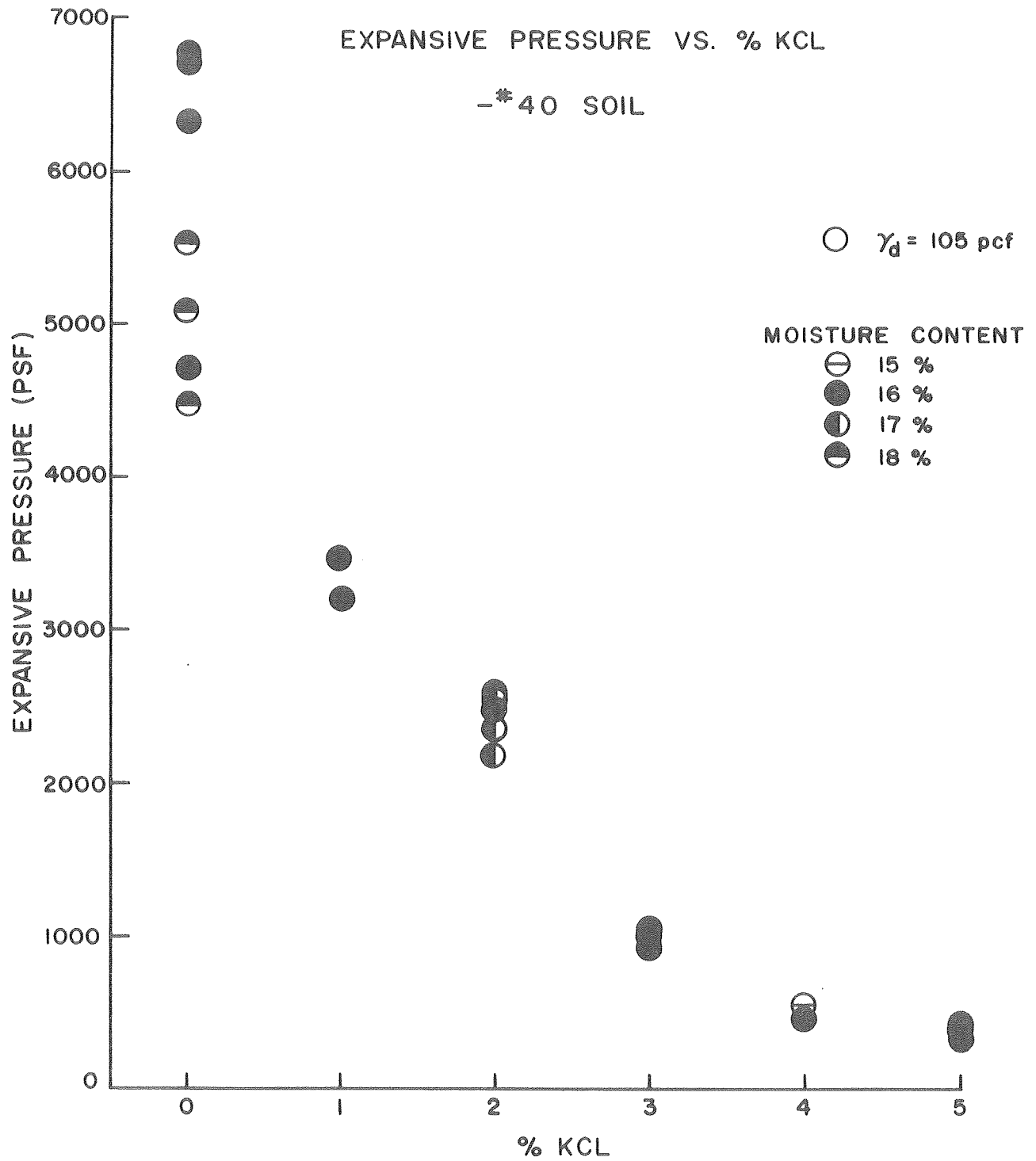


Figure 4

At the two ends of the compacted soil, metal electrodes were placed. A voltage of one volt per inch was used whenever electro-osmosis was employed. Solution was supplied at the anode and the test was run until the solution reached the cathode. The time required for the solution to migrate from anode to cathode was visually noted. In an attempt to combat the effects of capillary action, a longer tube was used, see Figure 5. In addition to visual observation, an attempt to monitor the movement of the solution front using electrical sensors was utilized. For a detailed discussion of the sensors, the reader is referred to Appendix B.

The results from both types of tube tests were quite similar. This indicates that the inherent problems of capillary and edge effects could not be eliminated in the laboratory tube studies, and therefore meaningful results for the rate of penetration of the solution could not be obtained. However, the treated samples were removed from the tubes and the expansive pressures were measured. In this way, a relative comparison of the effectiveness of the various wetting agents was obtained.

Table 1 shows how each of the wetting agents met the five aforementioned criteria. If a wetting agent was found to be unsuitable due to expense or solubility, no further tests were run.

Of the five wetting agents, propanol alcohol was eliminated because of the large quantities required to be effective and Ultrawet was eliminated due to its insolubility in KCl solution. Aerosol O.T. was found to have low solubility in KCl solution, and in addition, a

PERMEABILITY APPARATUS
SECTIONAL VIEWS

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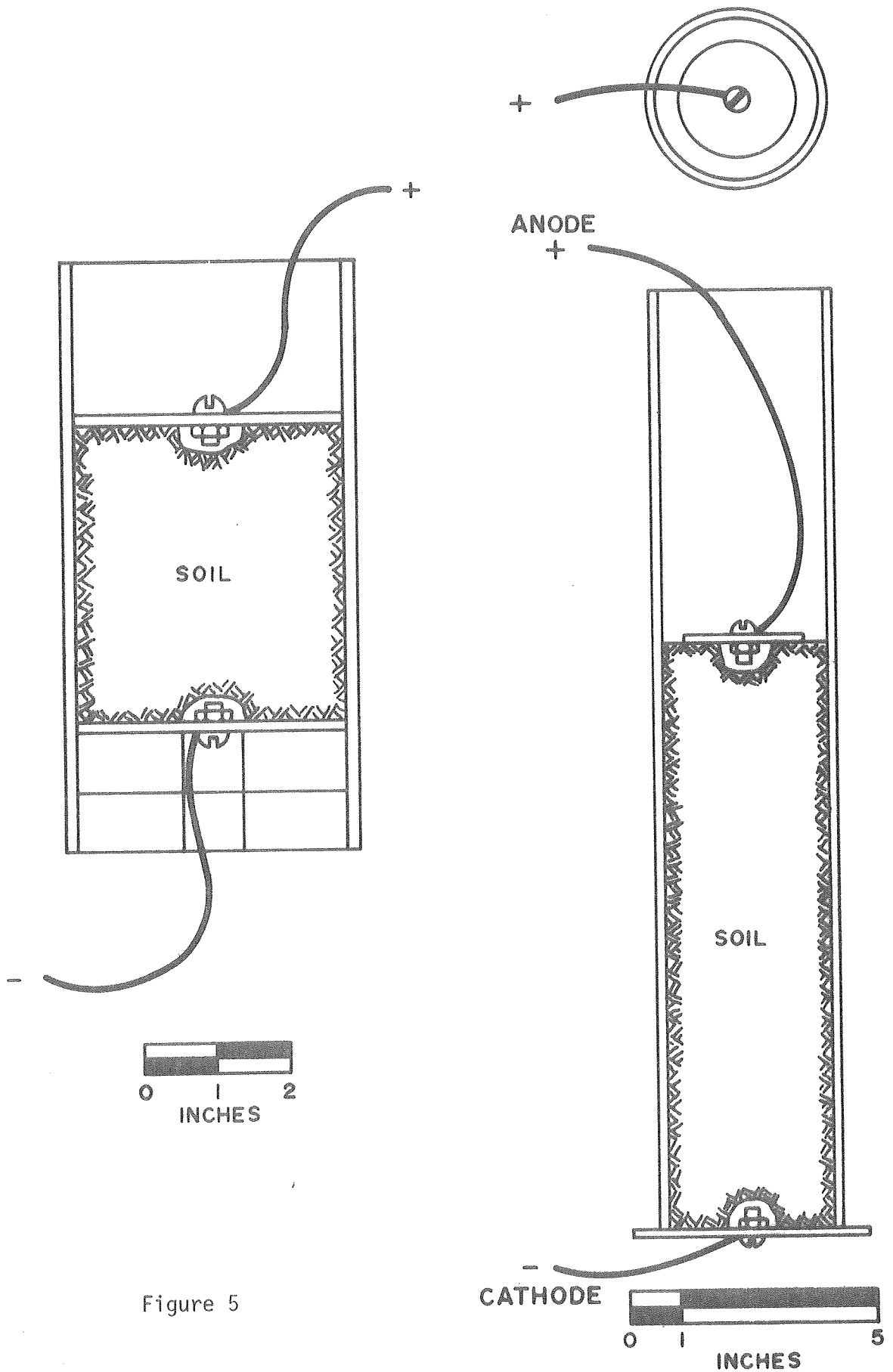


Figure 5

Table 1
COMPARISON OF WETTING AGENTS

| <u>Wetting Agent</u> | <u>Rate of Penetration</u> | <u>Compatibility with KCl</u> | <u>Effect of Wetting Agent on Expansive Press.</u> | <u>Amount Required</u> | <u>Ease of Mixing in Field</u> |
|----------------------|---|-------------------------------------|--|-------------------------------|--------------------------------|
| Alcohol | Substantially increased rate of penetration | No noticeable effects on solubility | Not measured | > 20% by weight | Very easy |
| Ultrawet | No effect | Nearly insoluble in KCl solution | Not measured | Could not get into a solution | Very difficult |
| Aerosol O.T. | Very slight increase | Nearly insoluble in KCl solution | No effect | ~ 0.5% by weight of water | Very difficult |
| Aerosol A.Y. | Possible slight increase | O.K. for quantity required | No effect | ~ 0.5% by weight of water | Difficult |
| C-61 | Increased rate of penetration | O.K. for quantity required | Slight decrease | ~ 0.5-1% by weight of water | Fairly easy |

KCl solution containing O.T. did not show a sufficient increase in penetration rate. This, coupled with the difficulty of mixing it, caused Aerosol O.T. to be rejected.

Figures 6, 7, and 8 show the results of rate of penetration for C-61 and Aerosol A.Y. In any discussion of tube testing, one should point out some of the inherent difficulties involved. First, the problem of attempting to model like parameters that exist in the field to the laboratory is enormous. Problems consist of size, orientation of grains, side effects, boundary conditions and many more. Because of these inherent difficulties, there was no discernible difference between the two wetting agents. Therefore, it was decided to test the two wetting agents, Aerosol A.Y. and C-61, in a small-scale field test. This test was initiated and completed in November, 1971.

SEEPAGE FRONT (8" CYL.)

A EO KCL
 B — KCL
 C EO H₂O
 D — H₂O

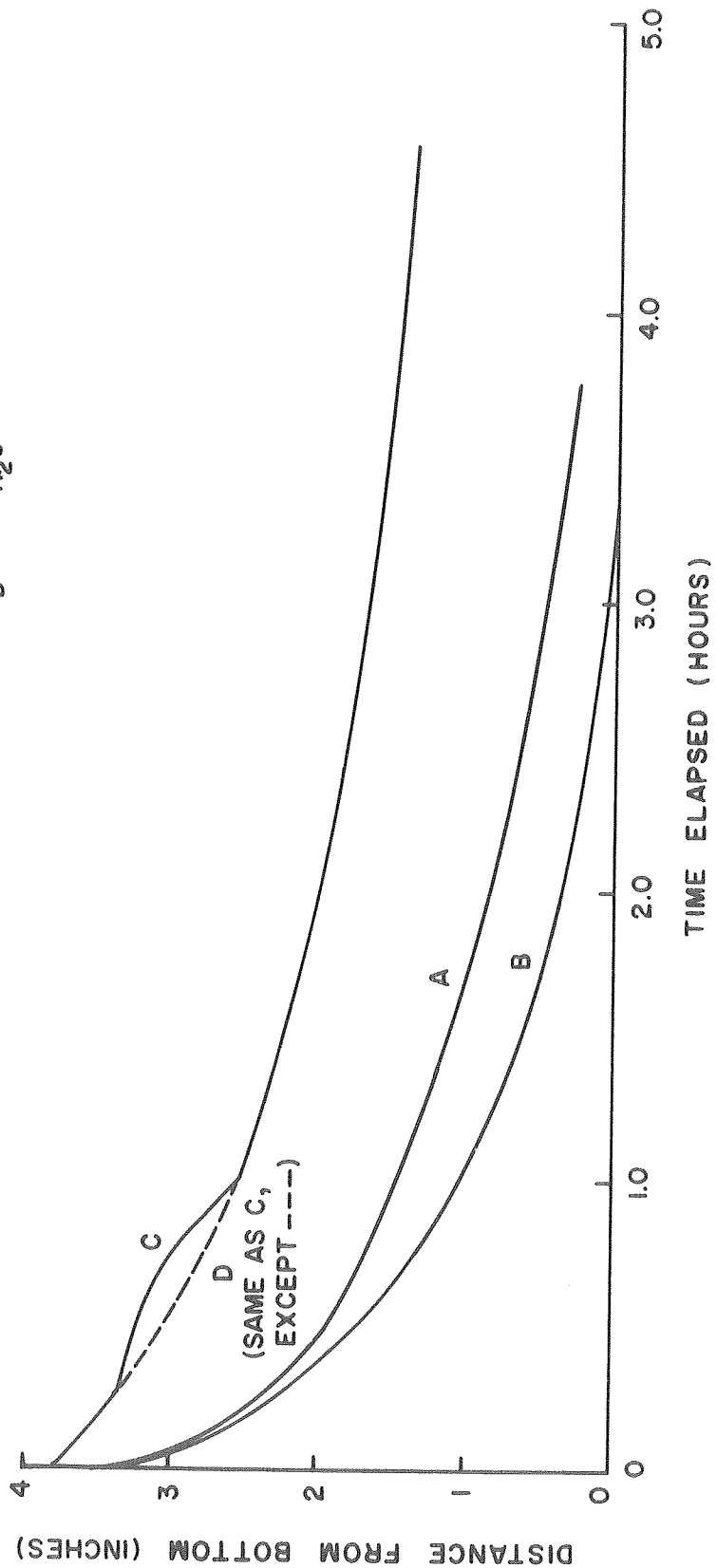


Figure 6

SEEPAGE FRONT (8" CYL.)

| | | | |
|---|----|----|------------------|
| A | EO | AY | KCL |
| B | — | AY | KCL |
| C | EO | AY | H ₂ O |

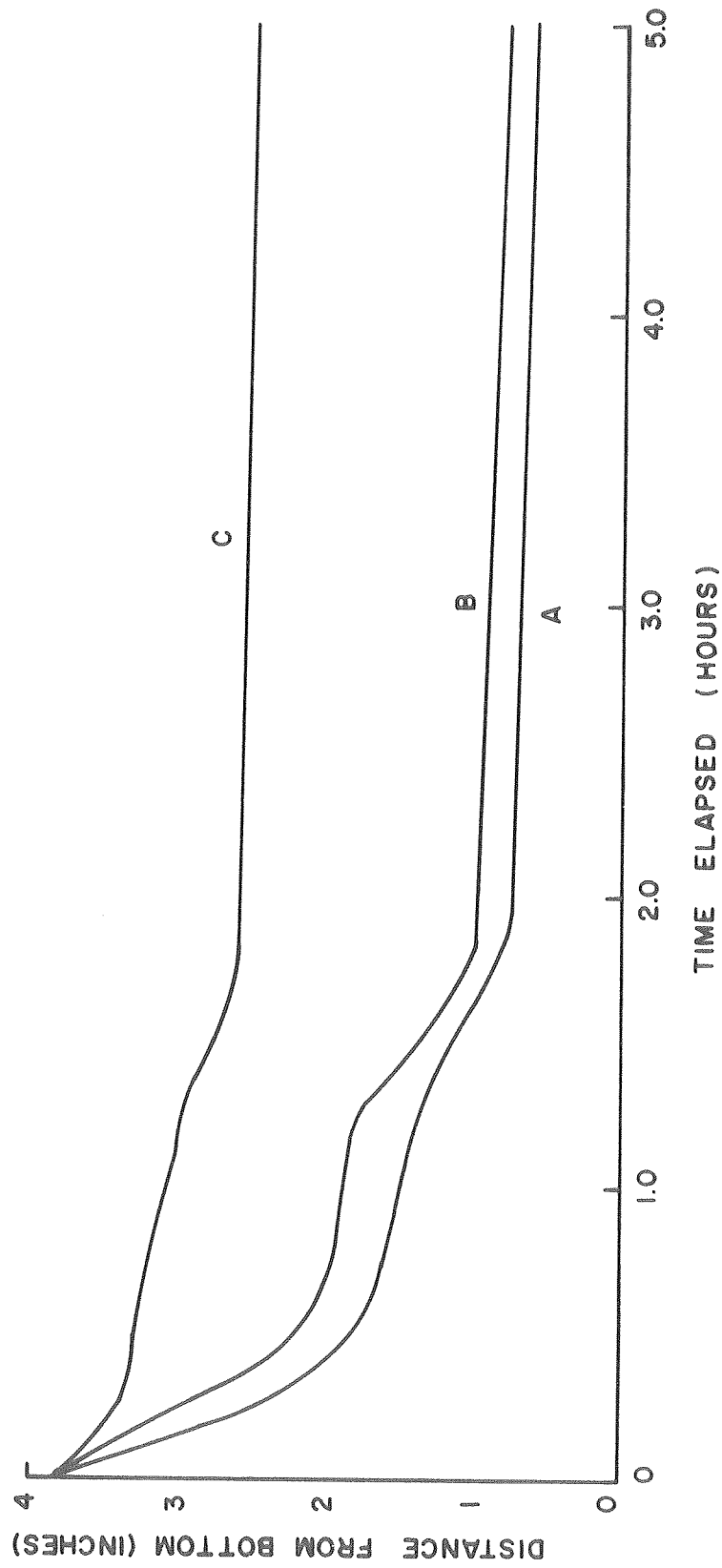


Figure 7

SEEPAGE FRONT (8" CYL.)

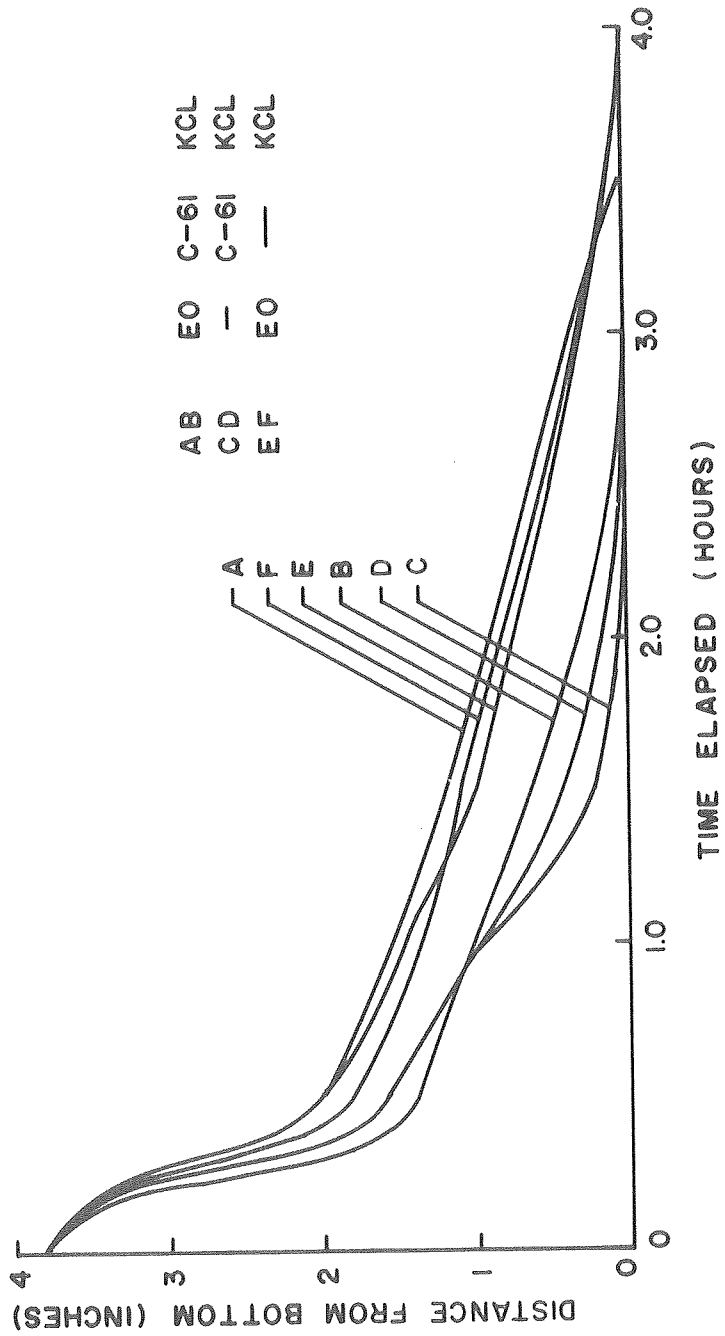


Figure 8

Chapter 4

SMALL SCALE FIELD TEST

PURPOSE

The purpose of the fall field test was to compare the effects of the wetting agents C-61 and Aerosol AY under actual field conditions.

SCOPE

The scope of the fall field test was:

1. To choose a test site, off the existing highway, near the location of the previously selected site.
2. To design, install and operate a field test to supplement laboratory work.
3. To sample the site after electro-osmosis treatment.
4. To test the samples for both a decrease in expansive pressure and increase in potassium content.

SITE SELECTION

An area was chosen in September 1971 approximately 100 yards east of the location of the site at milepost 489.5 where samples were taken for laboratory work in August 1971.

FIELD TEST

Design. The design of the field test consisted of five test plots. The layout of these plots is shown in Figure 9. Five separate test plots were necessary in order to investigate both the effect of

PLAN VIEW SMALL SCALE FIELD TEST SITE

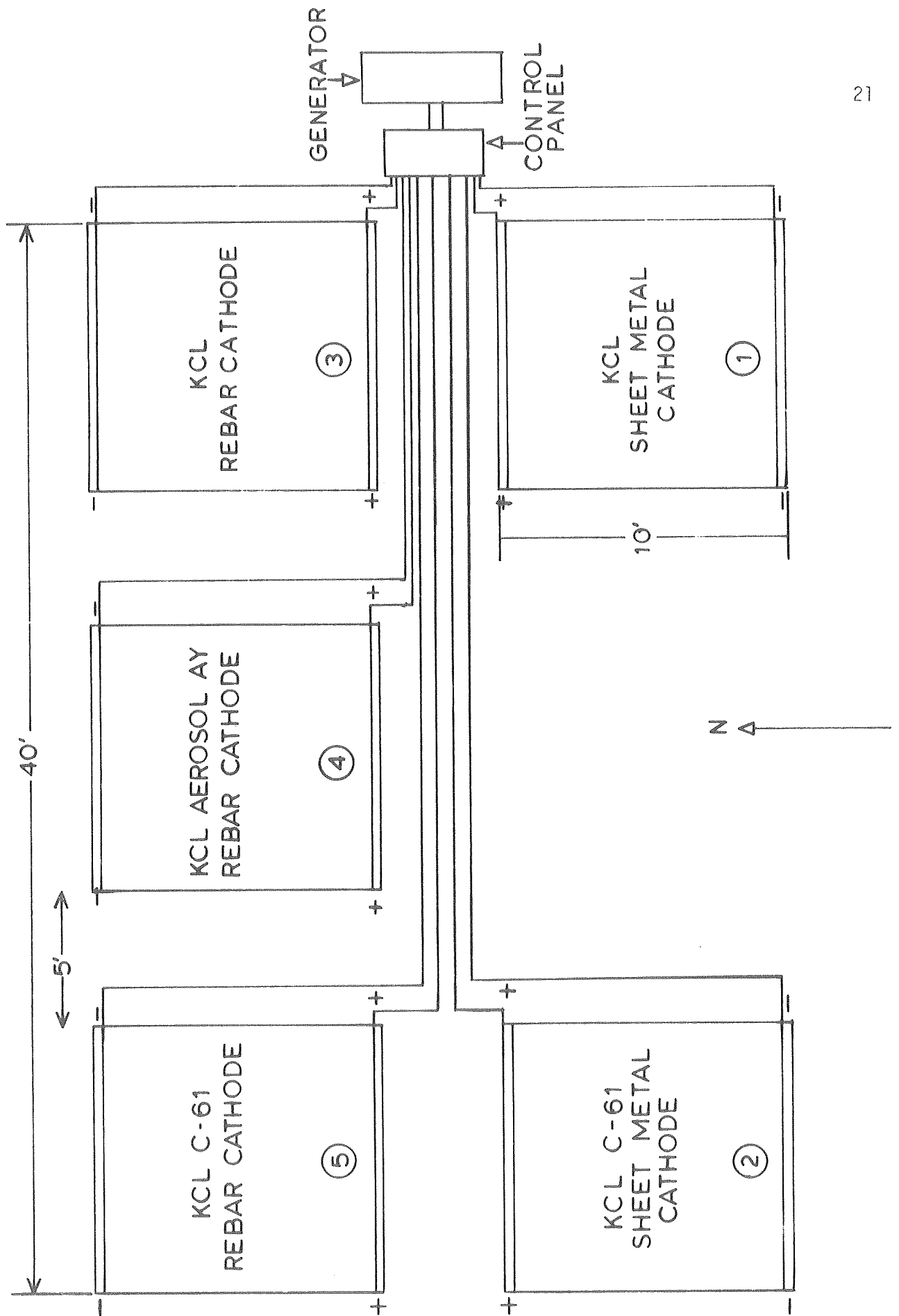


Figure 9

wetting agents and the type of metal cathode to be used in future field testing. The plots were divided in such a way so that two plots would contain sheet metal cathodes and three plots would use rebar cathodes. In addition, two plots would use C-61 wetting agent, one would test Aerosol AY, and two would employ only KCl solution without the use of an additive as a standard for comparison purposes. Plots two and five used sheet metal cathodes while plots one, three and four used rebar cathodes. The chemical solution for plots one and two contained one percent C-61 by weight. Solution for plot three contained one percent Aerosol AY by weight and the chemical solution for plots four and five contained no wetting agent.

The chemical solutions for all the plots contained 28 percent potassium chloride by weight of water. This percentage of KCl was chosen because it was felt that this was the maximum amount that would stay in solution under the ambient temperatures expected. Using this percentage, approximately two gallons of solution would be needed for every cubic foot of soil to effectively reduce the expansive pressure. However, since the purpose of the test was to compare wetting agents and the effect of type of metal cathode and not effectively treat the entire 10-foot by 10-foot plot, only 600 gallons of solution for each plot were used.

INSTALLATION

The site preparation was started on October 10, 1971. At this time, the site was leveled and the trenches dug. It was originally planned to completely set up the test section and immediately begin

operation; however, unseasonable snowfall forced the postponement of the installation of the anodes and cathodes until November, 1971.

The installation was completed on November 16 when the six-inch steel slotted pipe used as the anodes were placed in the previously prepared trenches approximately two and one-half feet below the surface and covered with gravel to a depth of one foot. The remaining trench was filled with clay and recompactd to approximately field density with the use of mechanical hand dampers. The cathodes were installed approximately ten feet from the anodes in two and one-half foot deep trenches. The trenches were then filled with clay and recompactd to field density by mechanical means. In this manner, all five installations were completed without difficulty by the evening of November 16. See Figure 10.

After installation of the electrodes was completed, the necessary electrical wiring was a simple matter to complete. A number 8 wire was run from each anode and cathode to a central control panel. The panel was connected to the 62.5 kw D.C. generator used as the source of power in the electro-osmosis portion of the field test. A voltage gradient of approximately 0.8 volts per inch was used for this test. For a complete discussion of the details and design of the panel and the selection of the voltage gradient, the reader is referred to the Phase I report, "Stabilization of Expansive Clays by Electro-osmosis and Base Exchange of Ions," Engineering Research Center, Arizona State University, 1965.

Simultaneously with the electrical portion of the installation, five 300-gallon water tanks were placed on prefabricated metal stands.

TYPICAL SECTION
SMALL SCALE FIELD TEST

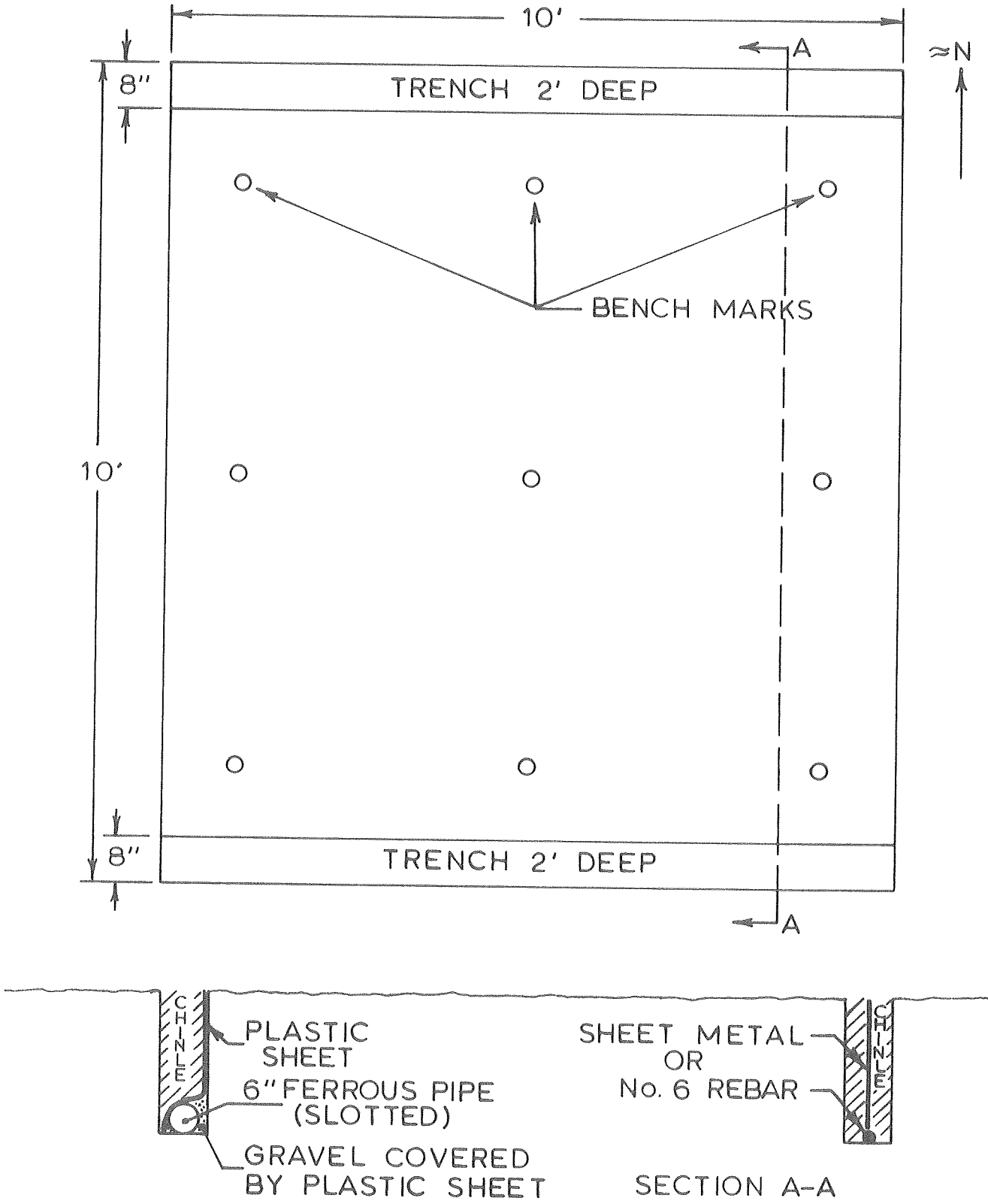


Figure 10

The stands and tanks were placed near the anode at the existing five plots. Each tank was connected to an anode with a 3/4-inch plastic pipe. A shutoff valve was installed on each tank to control the quantity of chemical solution flowing into the anode. This valve enabled the operator to not only control the rate of inflow but also it prevented overflowing of the slotted pipe anode.

OPERATION

It was anticipated that all 3000 gallons of KCl solution could be mixed in one day at the beginning of the operation. However, due to the extreme cold weather and limitation of the available equipment, only 600 to 900 gallons of solution could be prepared during an 8-hour shift. Therefore, by 5 p.m. November 16, 600 gallons of KCl with no wetting agent had been mixed and placed into the tanks for plots 1 and 2. The electro-osmosis treatment for these sites was started at this time and continued until completion of the test. By 12:30 p.m. the next day, an additional 600 gallons of KCl with C-61 had been placed into tanks for plots 3 and 4. Electro-osmotic treatment was initiated at this time. They also ran continuously until completion of the test. At 1 p.m. on November 18, an additional 600 gallons of KCl with Aerosol AY was added to tank 5 and the final section was included in the electro-osmotic treatment.

The slotted pipe anodes were kept full at all times and chemical solution was continuously supplied to each site until the entire 600 gallons allotted to each site was exhausted.

Electro-osmotic treatment ran without interruption from the time of start up of each plot until 8 a.m. November 20, 1971, at which time the test was completed.

SAMPLING

For the purpose of sampling, a trench was cut down the middle of each test section perpendicular to the electrodes to a depth of approximately four and one-half feet. From this trench, both the samples for chemical analysis and expansive pressure were taken. Figures 11 through 15 show the location of the chemical analysis samples.

TESTS

A chemical analysis for potassium was run on 102 of the samples taken from the test section. The tests were run by a commercial testing laboratory in Phoenix, Arizona, using the standard water soluble potassium test. In this test, the sample is diluted, one part sample to five parts water. After the potassium is in solution, the solution is analyzed using flame photometry. This method measures only excess potassium and thus does not account for any potassium in the clay structure. It is recommended that in the future the tests be run at a testing facility capable of completely dissolving the clay mineral and analyzing for the total potassium content. The results of the chemical analyses can be seen in Table 2 and Figures 16 through 20.

In addition to the potassium content measurements, a few representative expansive pressures were also measured. These samples were taken and the expansive pressures measured by the Arizona Highway Department. However, insufficient samples were taken to indicate the

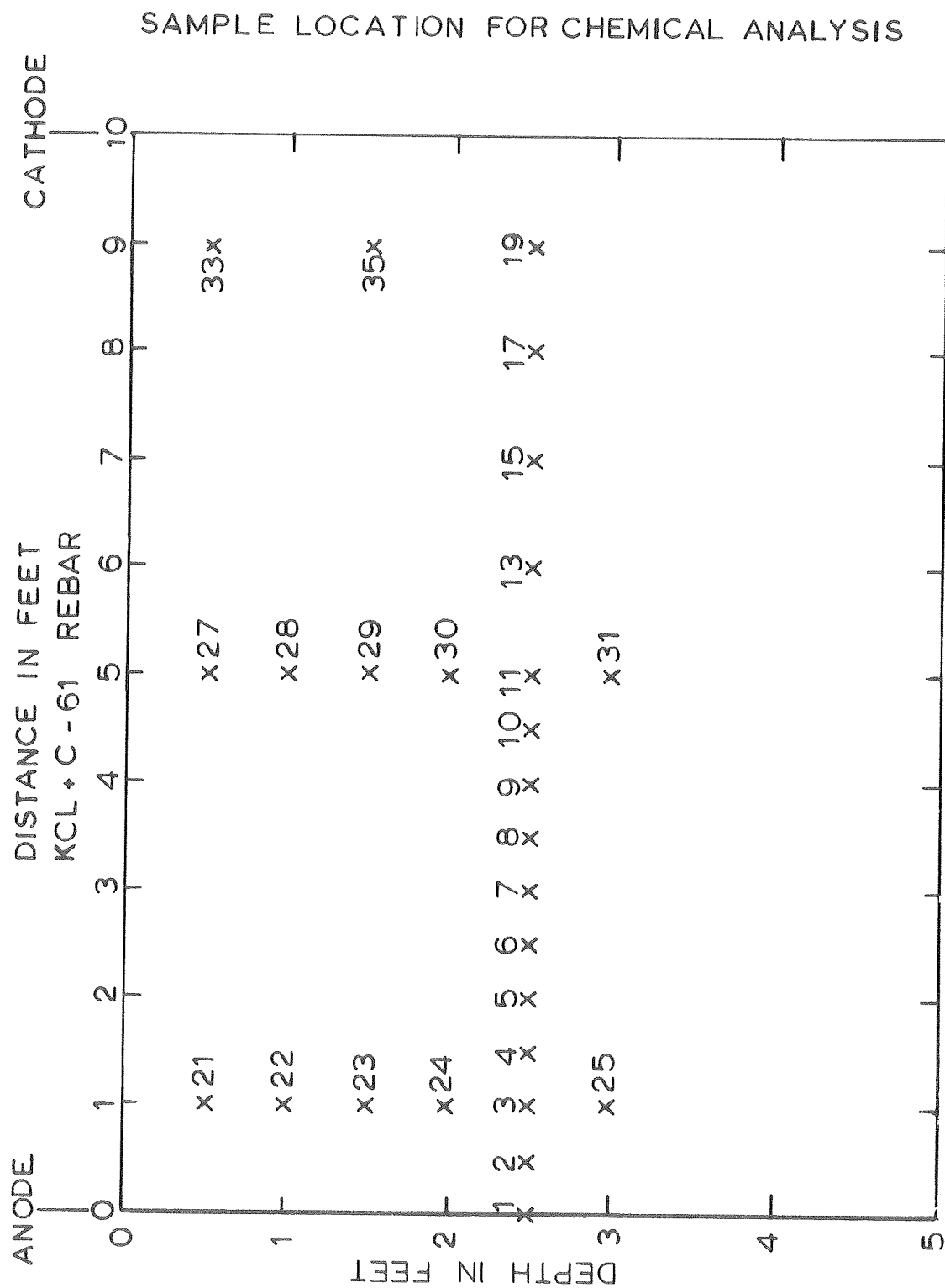


Figure 1i

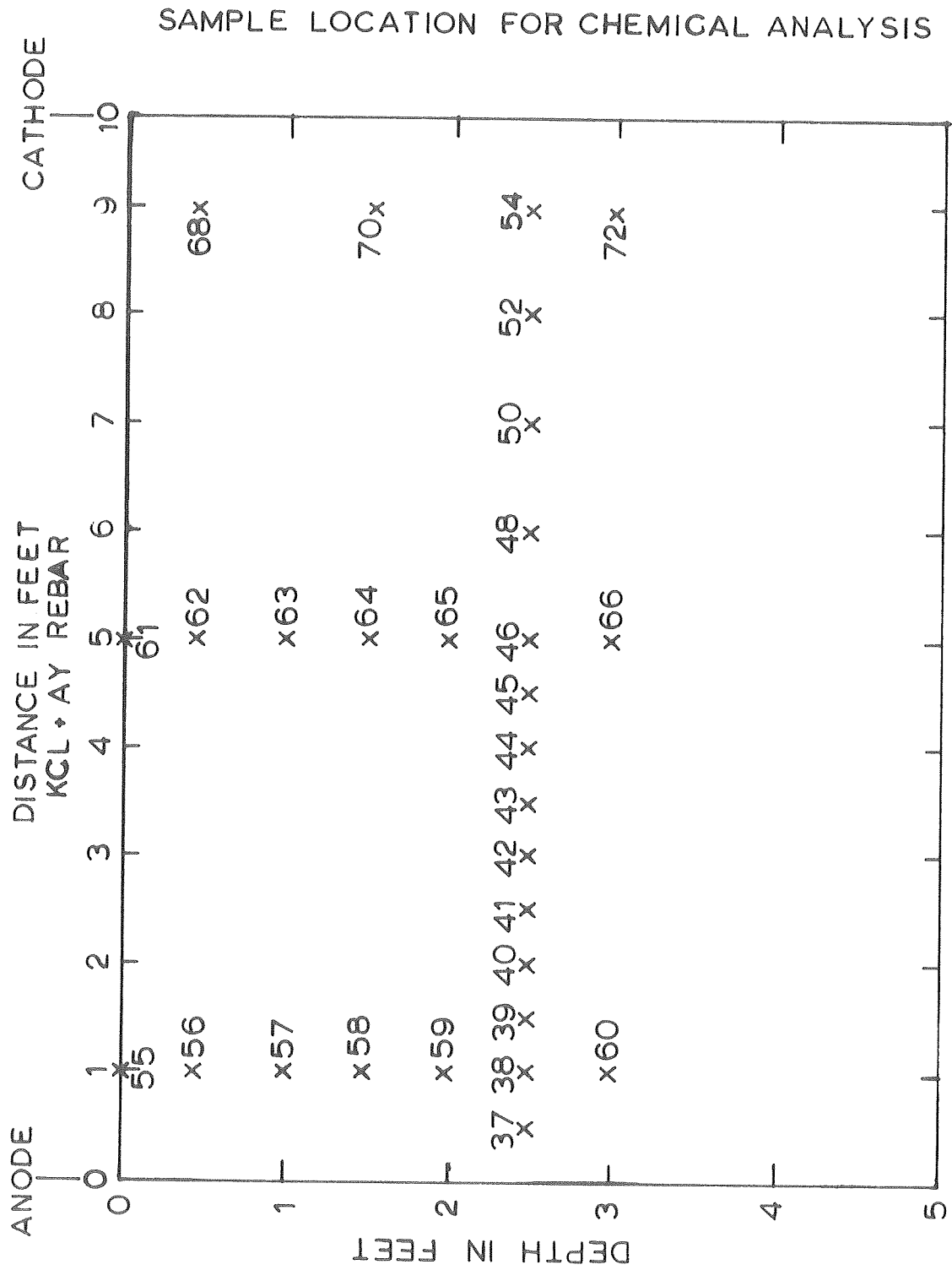


Figure 12

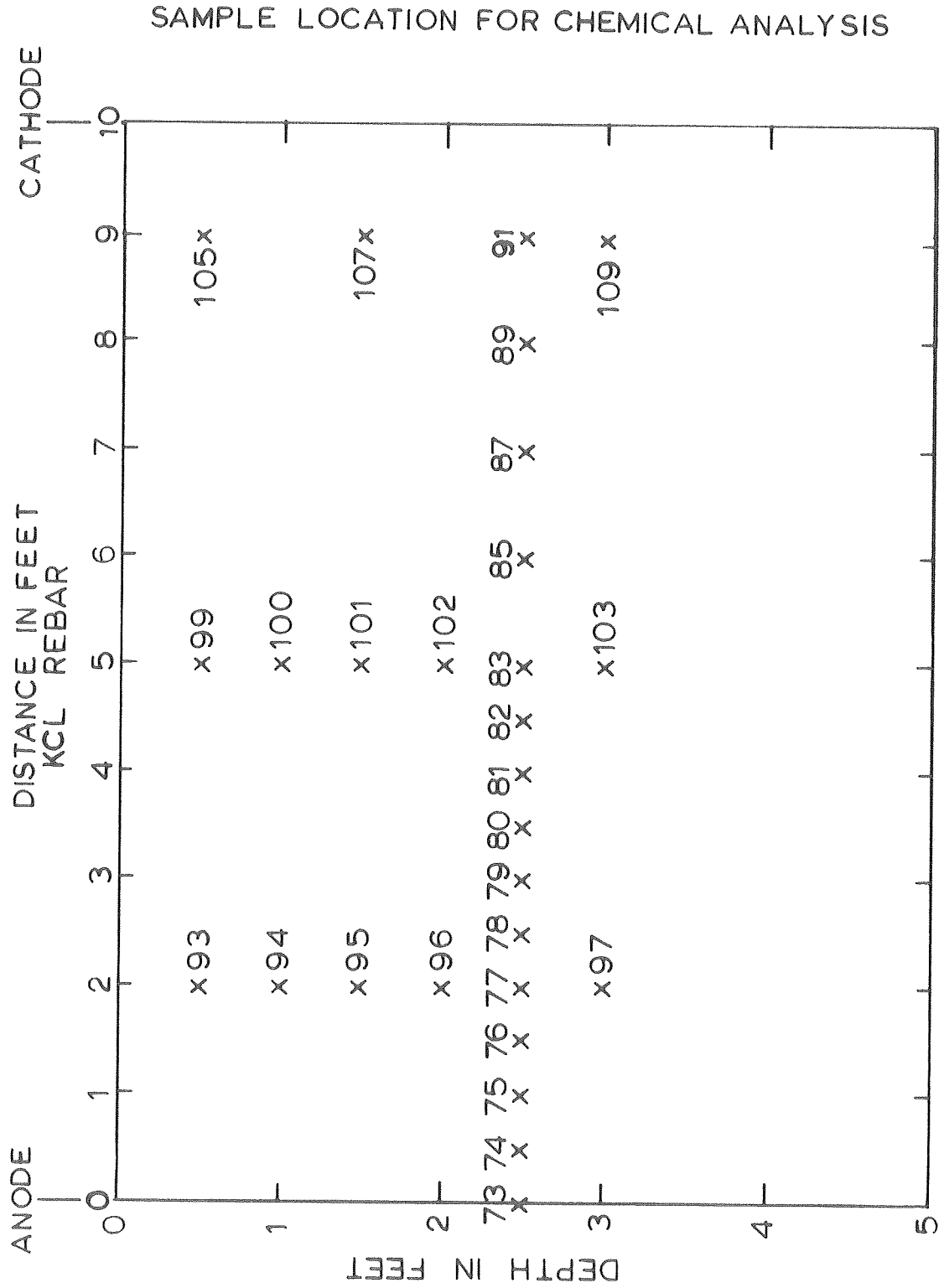


Figure 13

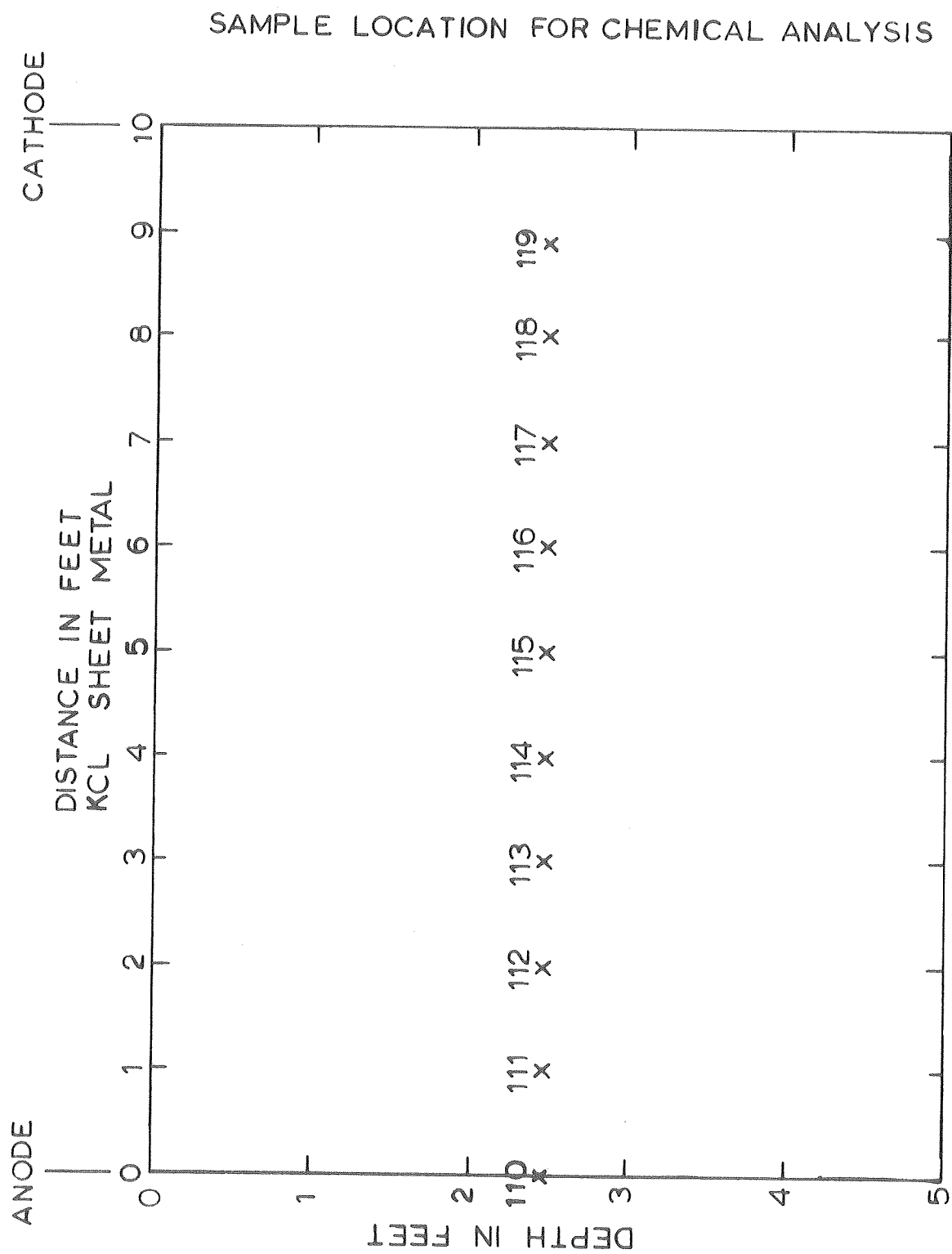


Figure 14

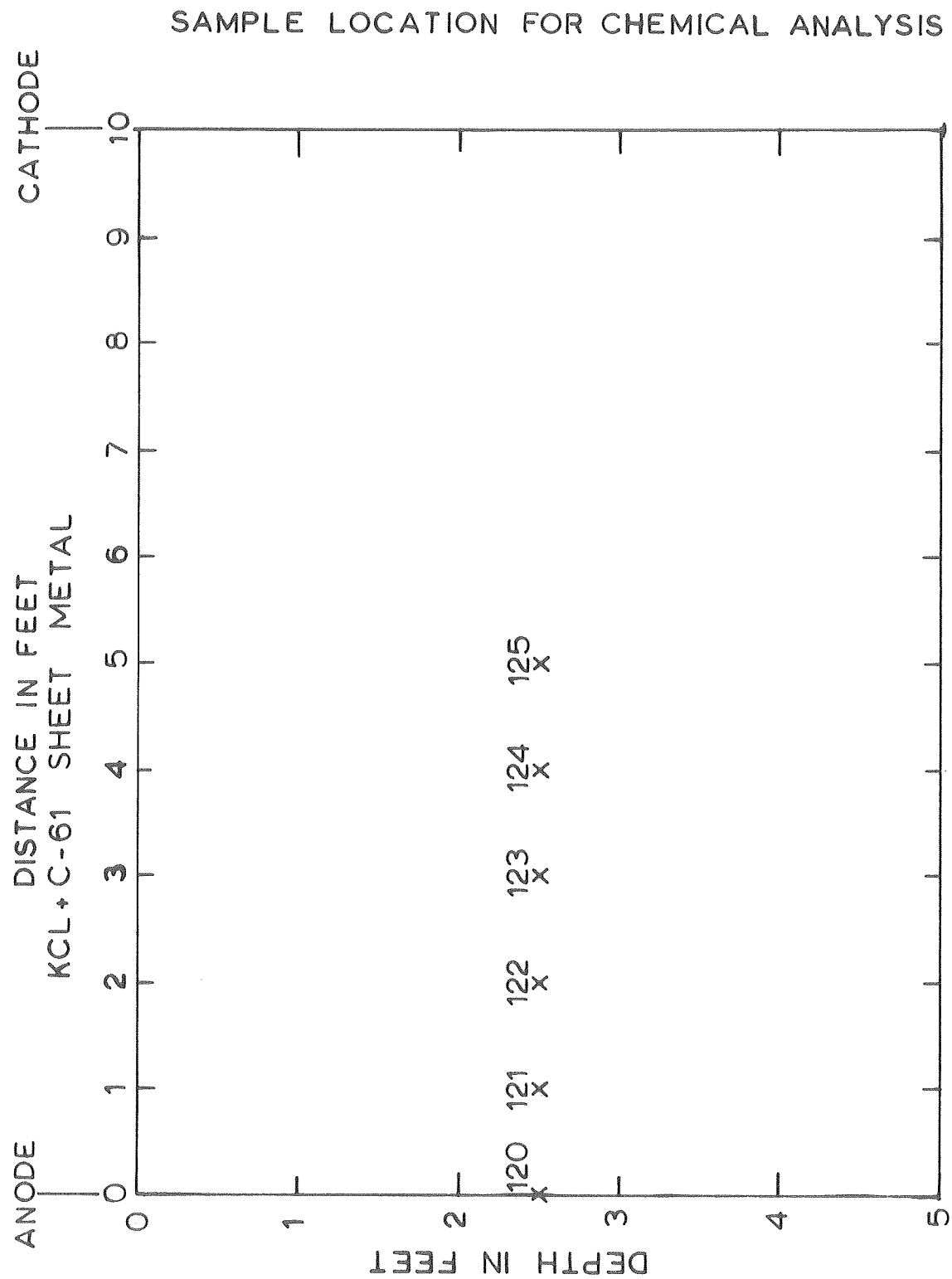


Figure 15

Table 2
EXCESS POTASSIUM CONTENT IN TREATED MATERIAL

| Sample No. | Potassium ppm | Sample No. | Potassium ppm | Sample No. | Potassium ppm |
|------------|---------------|------------|---------------|------------|---------------|
| * | | | | | |
| 1 | 9000 | 44 | 150 | 85 | 270 |
| 2 | 8500 | 45 | 150 | 87 | 580 |
| 3 | 4500 | 46 | 1150 | 89 | 560 |
| 4 | 1350 | 48 | 840 | 91 | 630 |
| 5 | 510 | 49 | 990 | 93 | 680 |
| 6 | 870 | 50 | 1050 | 94 | 190 |
| 7 | 280 | 52 | 560 | 95 | 350 |
| 8 | 740 | 54 | 1150 | 96 | 1650 |
| 9 | 120 | 55 | 14000 | 97 | 970 |
| 10 | 530 | 56 | 1500 | 99 | 50 |
| 11 | 630 | 57 | 1200 | 100 | 1550 |
| 13 | 130 | 58 | 1400 | 101 | 730 |
| 15 | 860 | 59 | 840 | 102 | 770 |
| 17 | 740 | 60 | 5000 | 103 | 700 |
| 19 | 690 | 61 | 310 | 105 | 80 |
| 21 | 2500 | 62 | 260 | 107 | 640 |
| 22 | 4250 | 63 | 510 | 109 | 660 |
| 23 | 4250 | 64 | 400 | 110 | 5100 |
| 24 | 3400 | 65 | 55 | 111 | 1800 |
| 25 | 2200 | 66 | 90 | 112 | 640 |
| 27 | 620 | 68 | 75 | 113 | 250 |
| 28 | 650 | 70 | 480 | 114 | 1050 |
| 29 | 620 | 72 | 560 | 115 | 890 |
| 30 | 560 | 73 | 1350 | 116 | 1050 |
| 31 | 620 | 74 | 680 | 117 | 1000 |
| 33 | 590 | 75 | 710 | 118 | 1000 |
| 35 | 80 | 76 | 680 | 119 | 900 |
| 37 | 1150 | 77 | 450 | 120 | 7800 |
| 38 | 1350 | 78 | 310 | 121 | 3600 |
| 39 | 920 | 79 | 920 | 122 | 260 |
| 40 | 880 | 80 | 580 | 123 | 730 |
| 41 | 440 | 81 | 420 | 124 | 730 |
| 42 | 620 | 82 | 680 | 125 | 850 |
| 43 | 450 | 83 | 710 | | |

*Untreated sample value is 55 ppm.

EXCESS POTASSIUM VS DISTANCE FROM ANODE

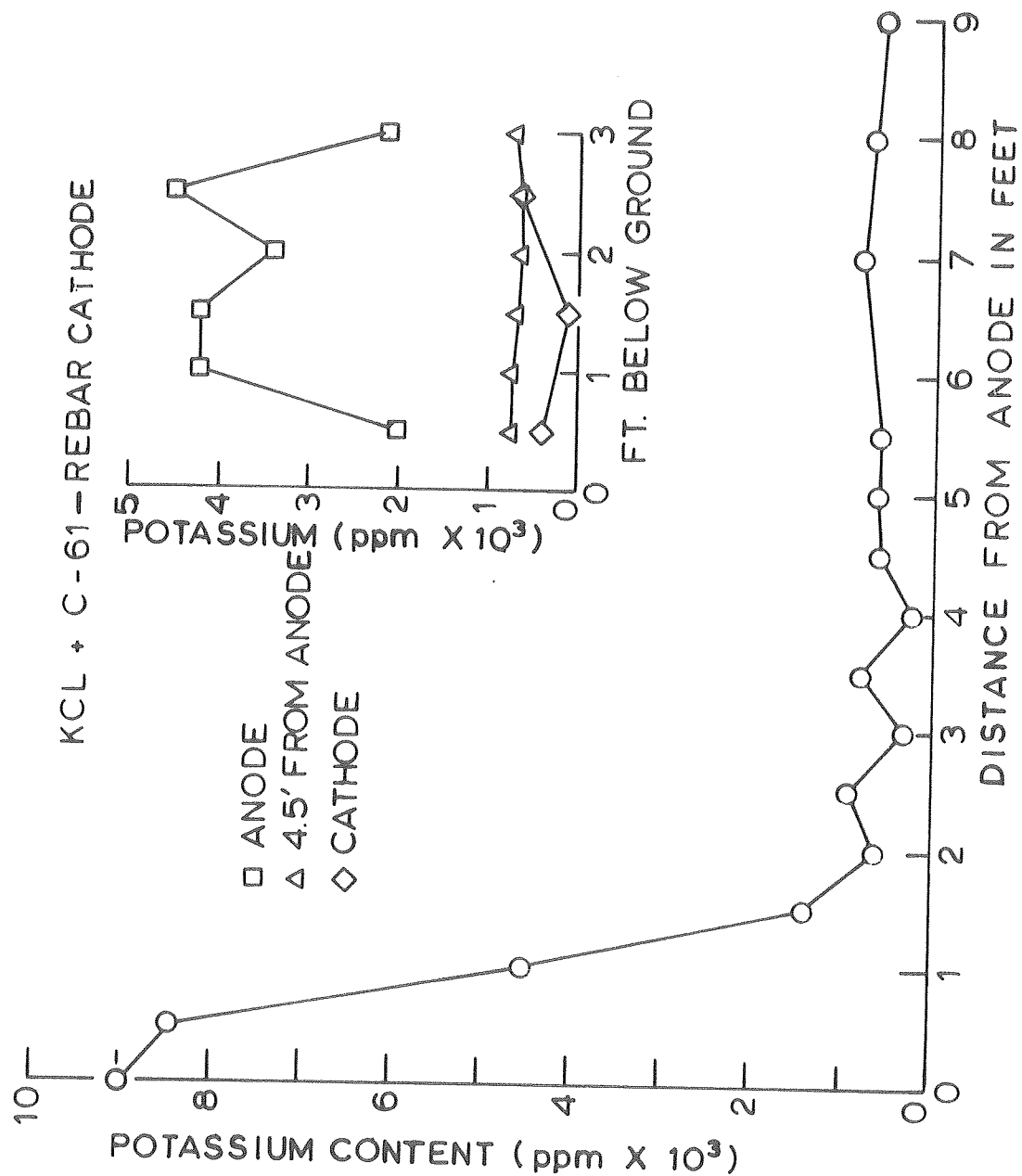


Figure 16

EXCESS POTASSIUM VS DISTANCE FROM ANODE

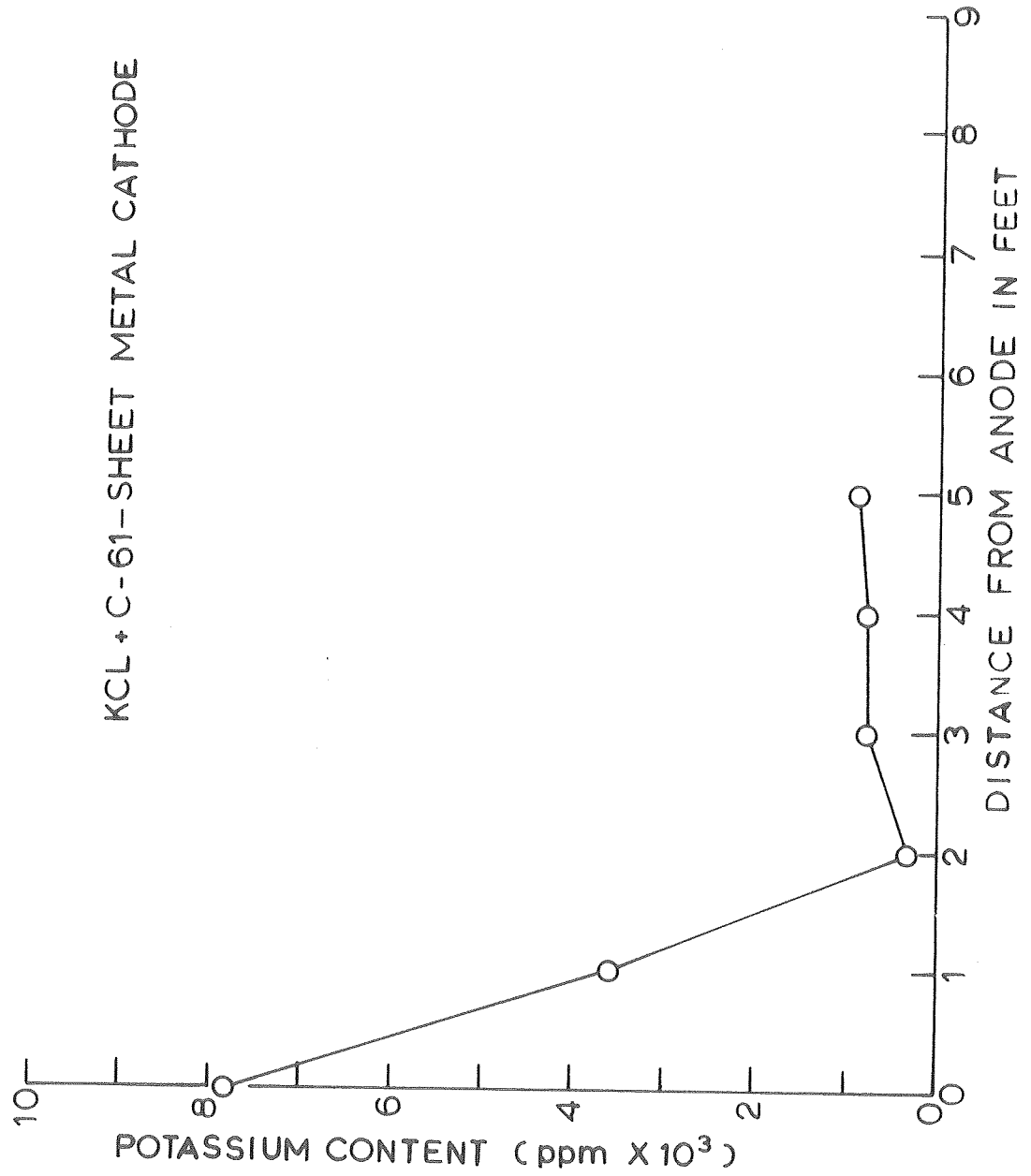


Figure 17

EXCESS POTASSIUM VS DISTANCE FROM ANODE

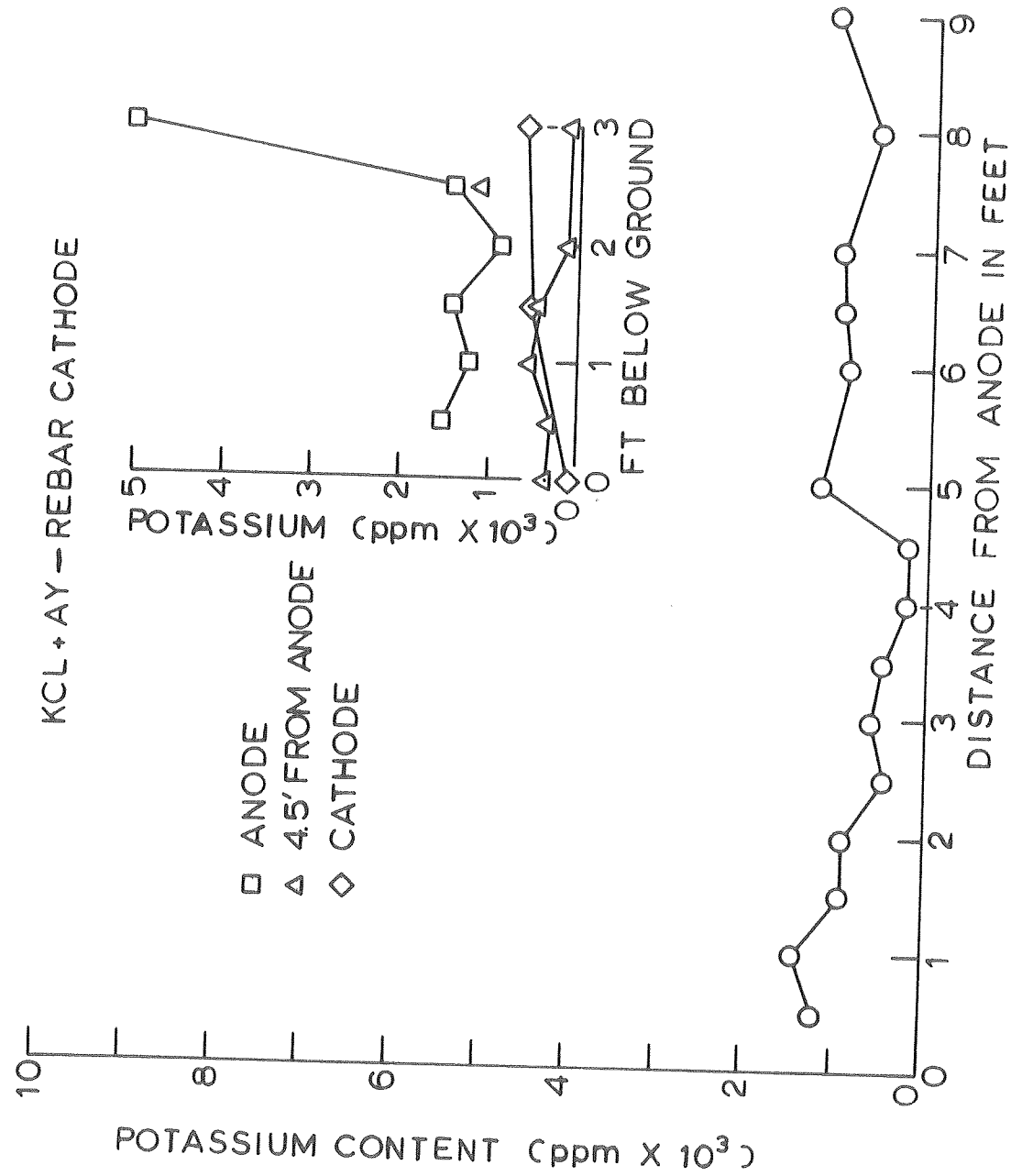


Figure 18

EXCESS POTASSIUM VS DISTANCE FROM ANODE

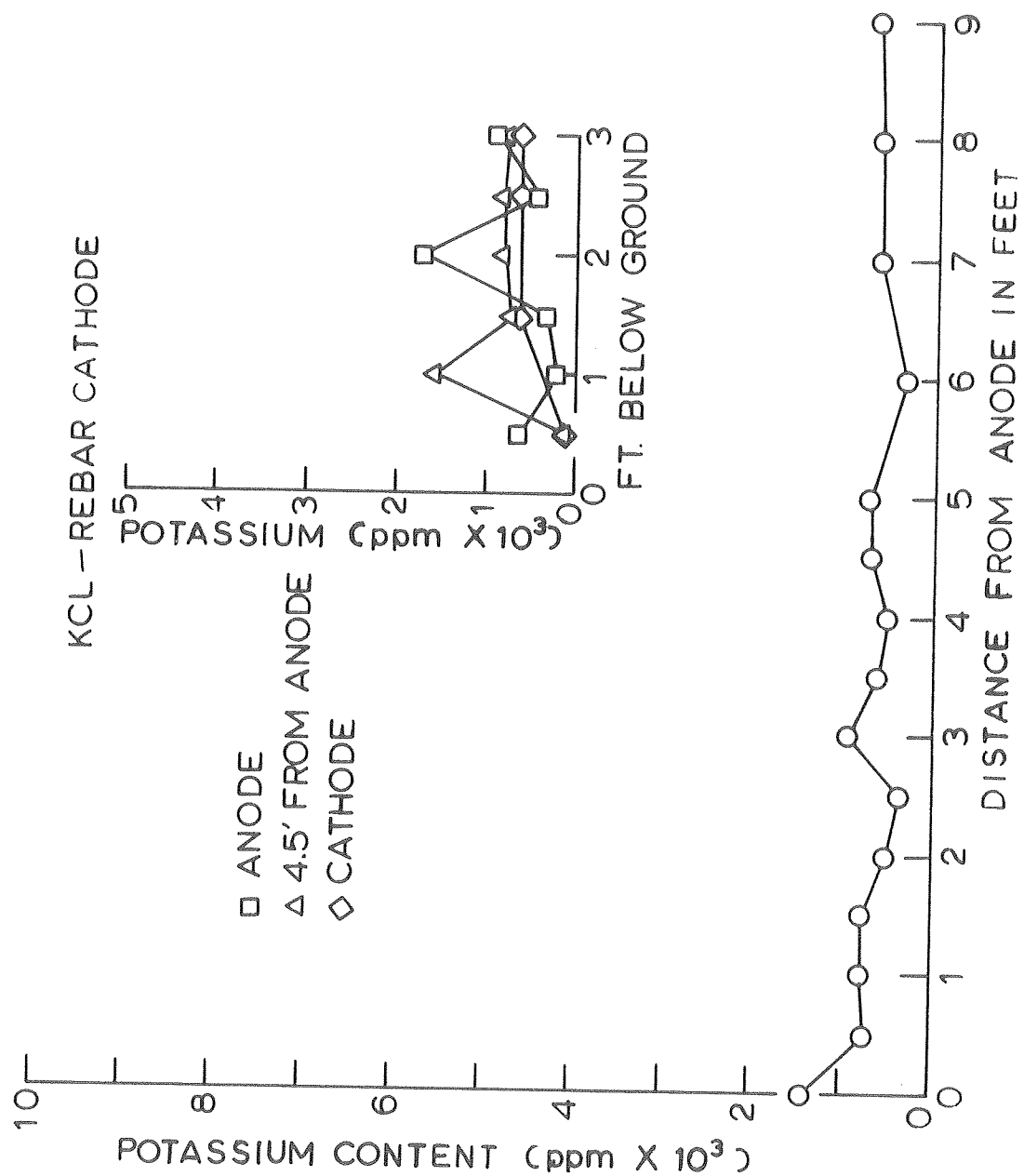


Figure 19

EXCESS POTASSIUM VS DISTANCE FROM ANODE

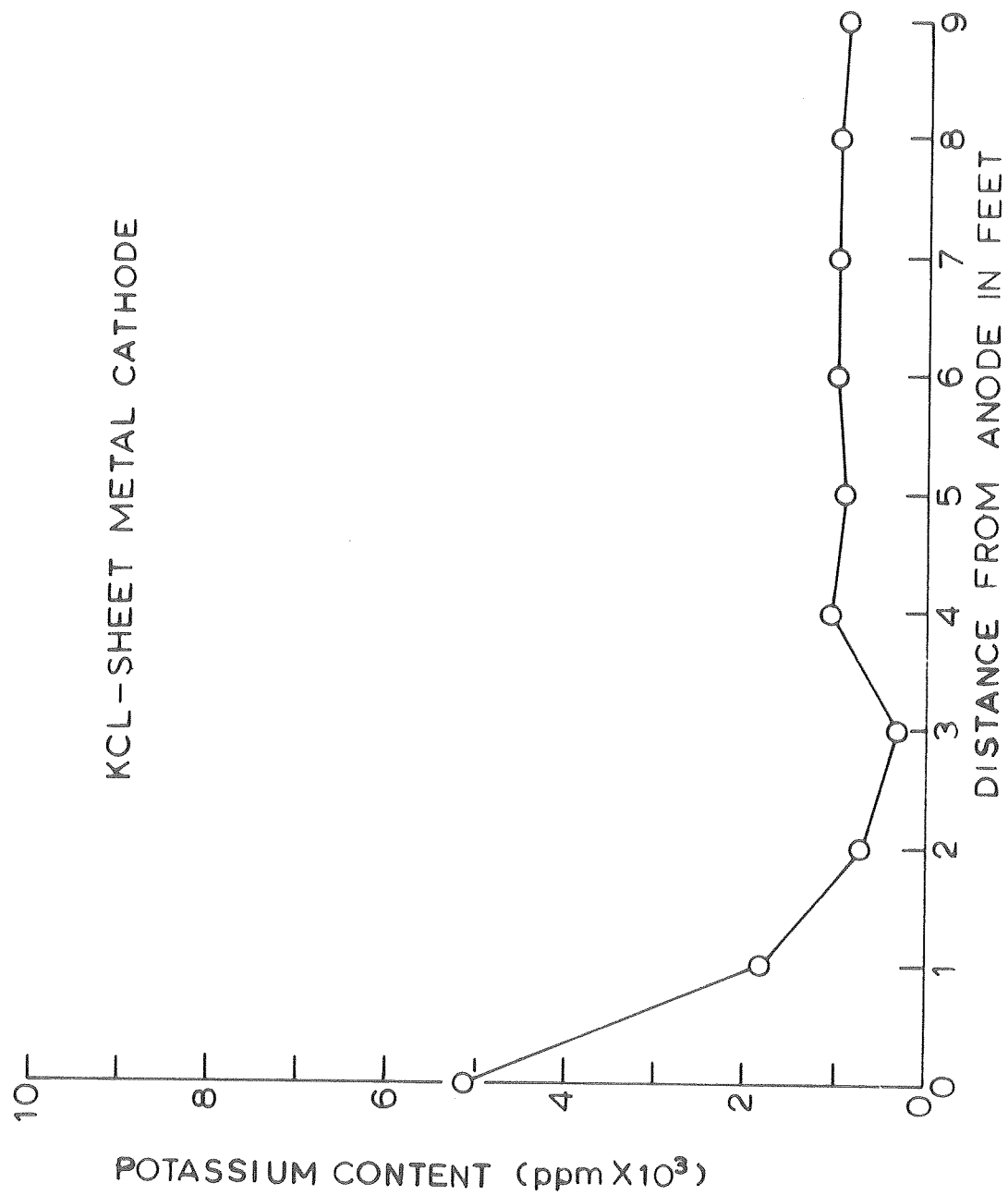


Figure 20

furthest penetration of the chemical solution. The results of these expansive pressure tests and the moisture contents can be seen in Table 3 and Figure 21.

CONCLUSIONS

Based on the chemical analysis of excess potassium and the expansive pressure tests, it appears that the wetting agent C-61 was the most effective. In addition, C-61 is much easier to handle than Aerosol AY. Thus in future applications it is recommended that the wetting agent C-61 be used.

Table 3
EXPANSIVE PRESSURES AND REDUCTION FACTORS OF TREATED MATERIAL

| Site No. | Sample Location | Depth ft. | Type of Treatment | R Value | Expansive Pressure #/ft ² | LL | PI | Moisture Content % | Reduction Factor |
|-----------|-----------------|-----------|-------------------|---------|--------------------------------------|----|----|--------------------|------------------|
| Untreated | | | | | | | | | |
| 1 | 1' from Anode | 0-1 | KCl | 16 | 4380 | 52 | 29 | 9.6 | 1.0 |
| | | 1-2 | KCl | -- | 1910 | 44 | 20 | 13.5 | 2.29 |
| | | 2-3 | KCl | -- | 2000 | 42 | 18 | 13.3 | 2.19 |
| | | 3-4 | KCl | -- | 1270 | 43 | 19 | -- | 3.45 |
| 2 | 1' from Anode | 0-1 | KCl | -- | 1910 | 42 | 18 | 12.9 | 2.29 |
| | | 1-2 | KCl + C-61 | -- | 1000 | NP | -- | 13.4 | 4.38 |
| | | 2-3 | KCl + C-61 | 53 | 910 | NP | -- | 13.4 | 4.81 |
| | | 3-4 | KCl + C-61 | -- | 1638 | 35 | 13 | 13.7 | 2.67 |
| 3 | 2' from Anode | 0-1 | KCl | -- | 1665 | 40 | 17 | 13.1 | 2.63 |
| | | 1-2 | KCl + C-61 | -- | 1665 | 39 | 16 | 12.2 | 2.63 |
| | | 2-3 | KCl + C-61 | -- | 1665 | 39 | 16 | 12.2 | 2.63 |
| | | 3-4 | KCl + C-61 | -- | 1665 | 39 | 16 | 12.2 | 2.63 |
| 4 | 2' from Anode | 0-1 | KCl | -- | 2002 | 43 | 20 | 12.3 | 2.19 |
| | | 1-2 | KCl | -- | 2180 | 44 | 20 | 12.4 | 2.01 |
| | | 2-3 | KCl | -- | 1820 | 41 | 17 | 12.9 | 2.41 |
| | | 3-4 | KCl | -- | 1580 | 45 | 21 | 12.5 | 2.77 |
| 5 | 4' from Anode | 0-1 | KCl | -- | 1547 | 37 | 13 | -- | 2.83 |
| | | 1-2 | KCl | -- | 1547 | 37 | 13 | -- | 2.83 |
| | | 2-3 | KCl | -- | 1547 | 37 | 13 | -- | 2.83 |
| | | 3-4 | KCl | -- | 1547 | 37 | 13 | -- | 2.83 |
| 6 | 2' from Anode | 0-1 | KCl + AY | -- | 1729 | 49 | 25 | 13.2 | 2.53 |
| | | 1-2 | KCl + AY | -- | 2730 | 51 | 27 | 12.4 | 1.60 |
| | | 2-3 | KCl + AY | -- | 1729 | 47 | 24 | 12.6 | 2.53 |
| | | 3-4 | KCl + AY | -- | 1310 | 44 | 22 | 12.6 | 3.34 |
| 7 | 5' from Anode | 0-1 | KCl + AY | -- | 1893 | 44 | 21 | 12.3 | 2.31 |
| | | 1-2 | KCl + AY | -- | 1893 | 44 | 21 | 12.3 | 2.31 |
| | | 2-3 | KCl + AY | -- | 1893 | 44 | 21 | 12.3 | 2.31 |
| | | 3-4 | KCl + AY | -- | 1893 | 44 | 21 | 12.3 | 2.31 |
| 8 | 1' from Anode | 0-1 | KCl + C-61 | -- | 1183 | 34 | 11 | 14.5 | 3.70 |
| | | 1-2 | KCl + C-61 | -- | 2548 | 42 | 19 | 13.1 | 1.72 |
| | | 2-3 | KCl + C-61 | -- | 1365 | 33 | 10 | 13.5 | 3.21 |
| | | 3-4 | KCl + C-61 | -- | 2548 | 48 | 25 | 13.8 | 1.72 |
| 9 | 4' from Anode | 0-1 | KCl + C-61 | -- | 2002 | 52 | 28 | 14.5 | 2.19 |
| | | 1-2 | KCl + C-61 | -- | 2002 | 52 | 28 | 14.5 | 2.19 |

EXPANSIVE PRESSURES SMALL SCALE FIELD TEST

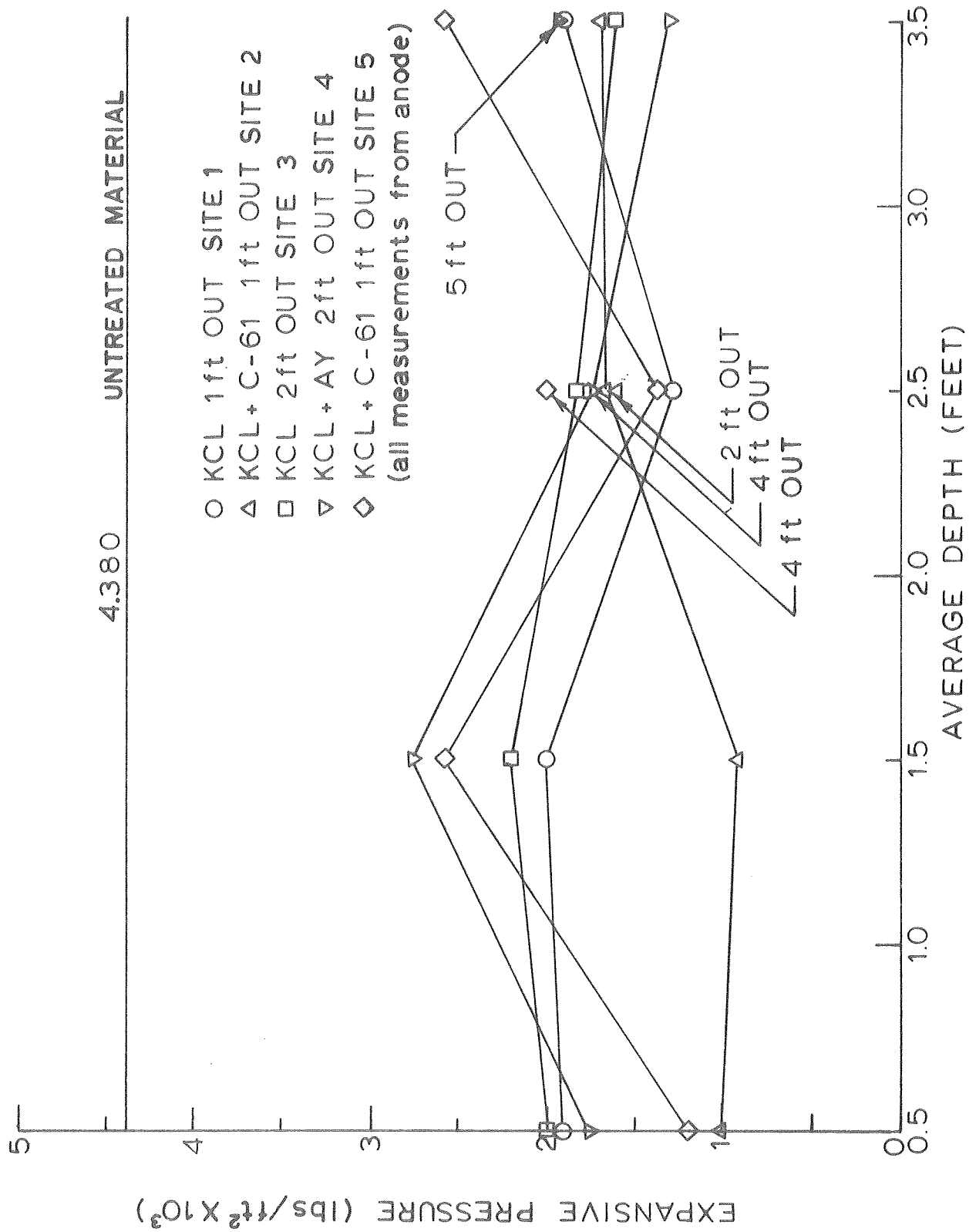


Figure 21

Chapter 5

MODEL STUDIES

GENERAL

The purpose of the model studies was to determine the following:

1. The shape of the potassium chloride solution front as it moved through the soil for two different electrode arrangements.
2. The relative velocities of the fronts for the two different arrangements.
3. The total area covered by the two different arrangements.

From this data it is hoped that the most efficient method of electro-osmosis stabilization could be determined.

MODEL PREPARATION

It was decided to try two different arrangements. These were electrodes spacing and method of supplying chemical solution. Model No. 1 consisted of vertical cathodes and a single vertical anode used as the solution well. Model No. 2 was designed to have a horizontal anode placed in a 6-inch deep trench. The cathodes for this model were 3 rebars driven vertically approximately 20 inches from the anode. Both models used a solution of 28% potassium chloride by weight and 1% C-61 by weight. As in previous tests, a voltage gradient of 1 volt per inch was used.

A 15" by 30" by 24" steel model was used to contain the statically compacted soil, see Figures 22 and 23. This steel mold was lined with 1/4" plywood on three sides and 1/2" plexiglas on the remaining side. The 1/2" plexiglas was used for one side of the model in an attempt to visually follow the solution front as it moved through the soil mass. In addition, a heavy gauge plastic sheet was placed next to the wood and plexiglas. The reason for placing the plastic liner inside the model was to reduce the possibility of making an electrical contact with the steel mold and thus causing a short circuit. During compaction of the model and during the test, Ames dials were positioned along side the model to measure lateral strain. While a maximum of 0.2 inches of deflection occurred on dials positioned along the plexiglas side during compaction, no strain was observed during the period the model was undergoing electro-osmotic treatment.

Except for a slight variation in the positions of the moisture sensor and the different electrode arrangements, both models were prepared in the same manner. The preparation of soil for treatment in the model began by obtaining a 600-pound representative sample of the previously prepared untreated material from U.S. 89 at milepost 489.5. This material was divided into 60-pound batches and combined with sufficient distilled water to increase the moisture content to 16 percent. The moist soil was thoroughly mixed, placed in large plastic bags and allowed to cure for three days. The model was designed to be compacted in three equal lifts. The material for each lift was placed in the previously prepared mold. The sensors (see Appendix B) were placed in

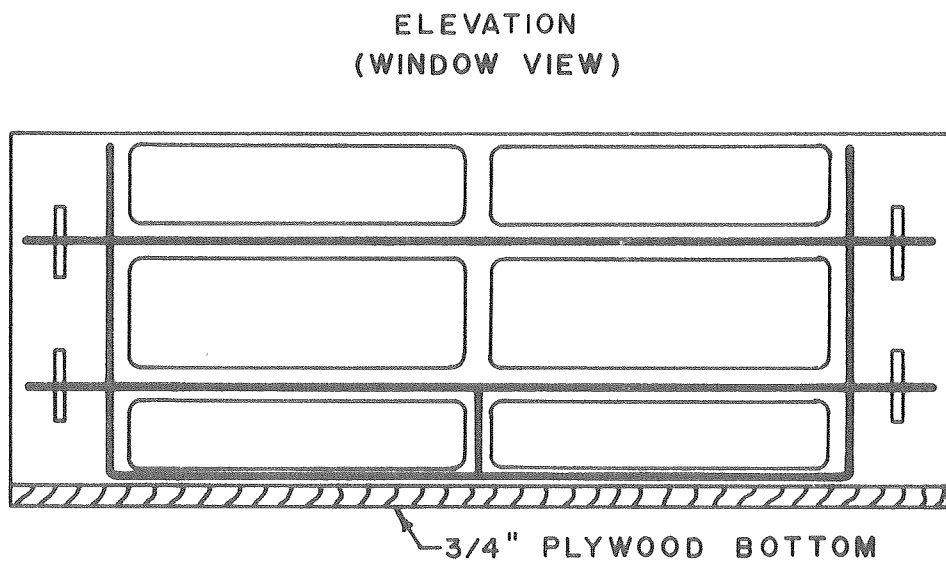
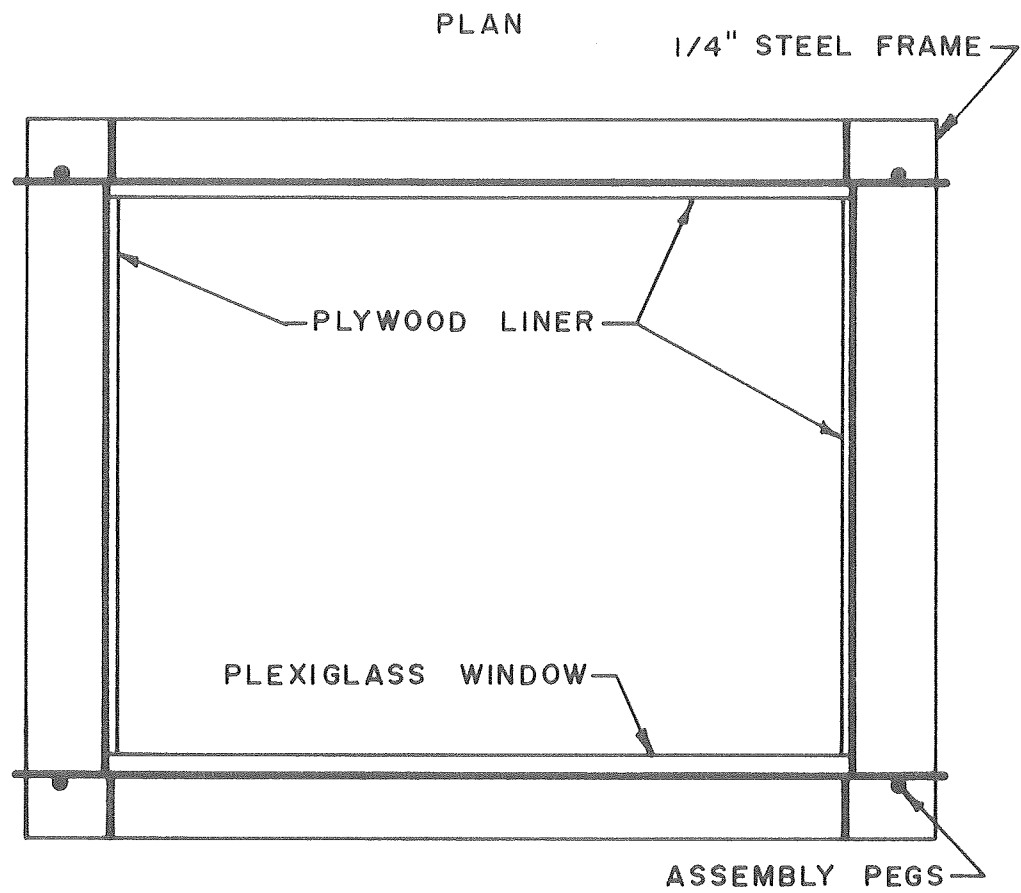


Figure 22

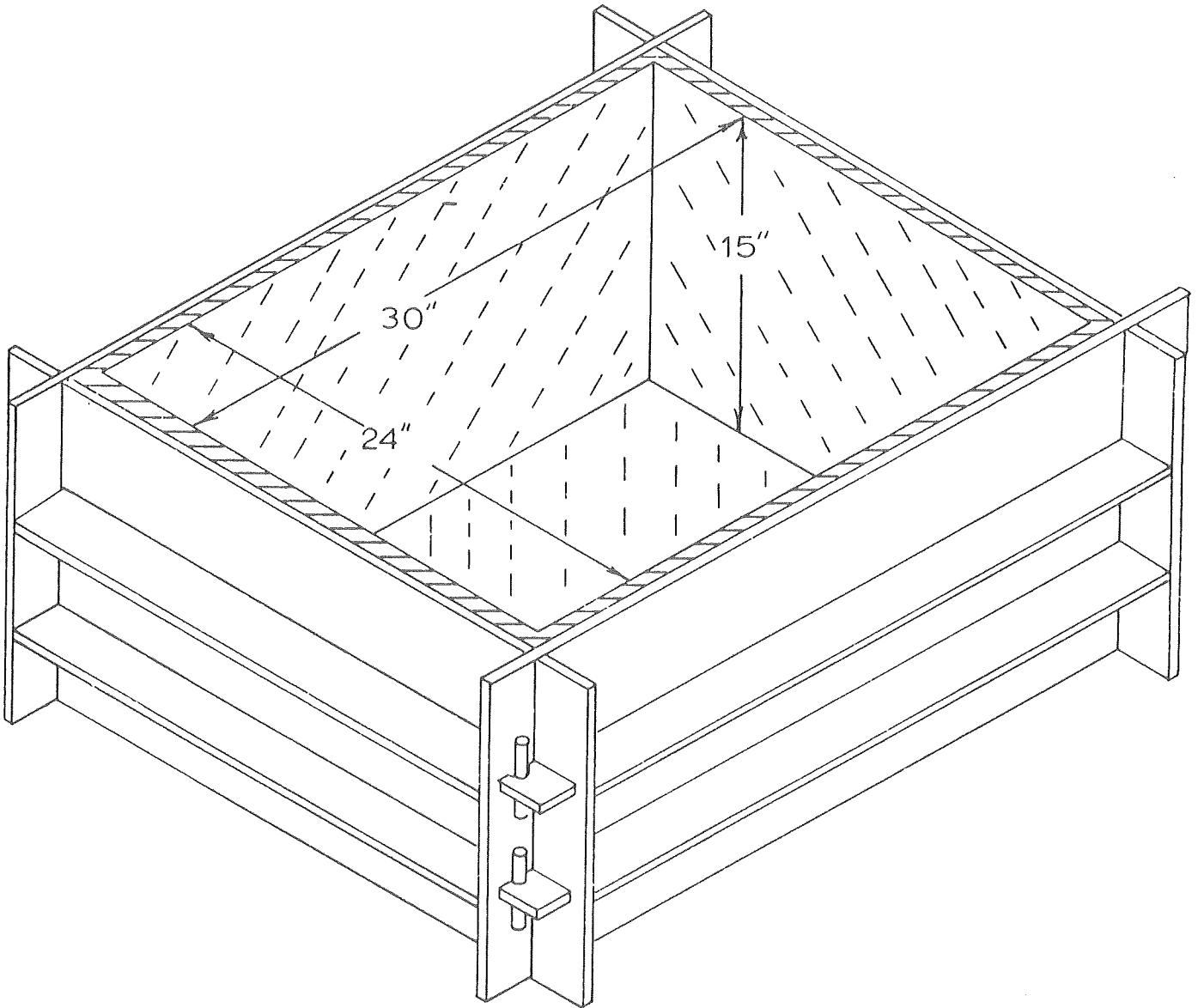


Figure 23
Model Study Apparatus

the soil, numbered and mapped as to location, then the lift was compacted using a 20" x 23" x 1/2" steel loading plate and the 300,000 pound Universal testing machine at the Arizona State Highway Department Central Laboratory. Sufficient vertical load was applied to compact the soil to a density of 105 pounds per cubic foot. After compaction of the first lift and before the next lift was placed, the compacted surface was thoroughly scarified to insure that a uniform bond would be obtained with the next higher layer. The sensors were placed in each lift before compaction, and their location mapped. The process was repeated until the final lift had been placed. Upon completion of the compaction operation, the model was returned to Arizona State University where the electrodes were installed and the electro-osmotic portion of the model test begun.

MODEL ONE

Model No. 1 was constructed so that electrode configuration in which positive (anode) and negative (cathode) electrodes were placed vertically could be studied. The compacted soil was prepared for treatment by driving the 11-1/2" x 3/8" solid steel rods which were used as negative electrodes. The first negative electrode was located six inches from the short side and five inches from the long side of the model. The remaining three cathodes were placed in a similar position in the model. A single positive electrode was used in this model, and it was located in the center of the mold. To install the positive electrode, a two-inch diameter hole was augered to a depth of six inches. A 7-1/2 inch long by 1 inch diameter slotted metal pipe was used for the positive electrode.

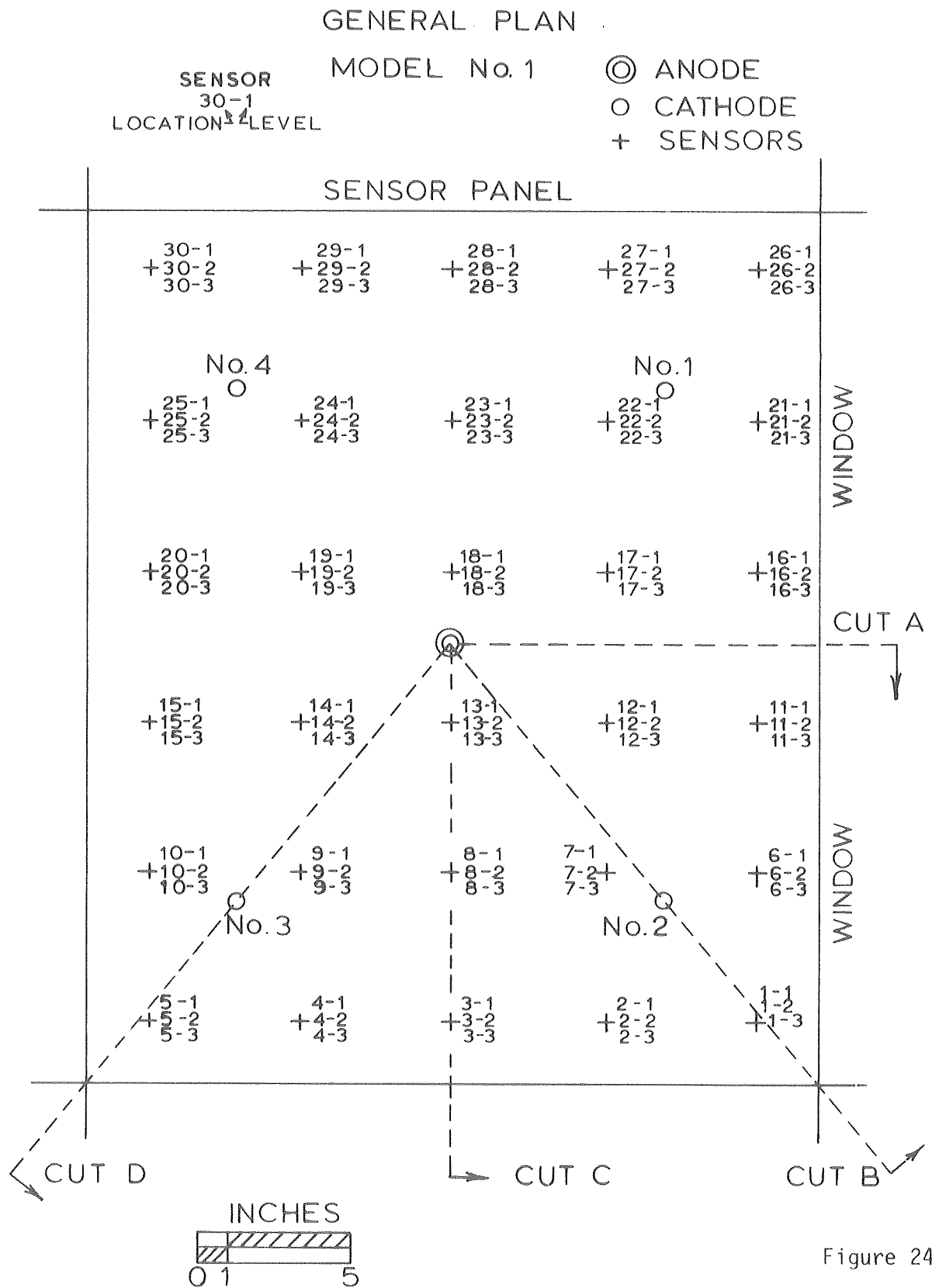
This pipe was driven the last 1/2 inch to insure that it was held firmly in place. A sand blanket was poured in the void between the casing and the compacted soil to provide a uniform media for flow from the pipe casing to the soil. For a plan view of Model No. 1, see Figure 24.

Both the anode and cathodes were then connected to the portable 30-volt D.C. power supply which was used throughout the model testing program to maintain the required voltage gradient of one volt per inch. The sensors were then connected to the control panel and the initial resistance was recorded. After completion of the wiring, the top of the model was covered with a plastic sheet, which was taped in place, to help reduce evaporation losses.

MODEL TWO

Model No. 2 was constructed to study treatment effects due to an electrode configuration of a horizontal anode and vertical cathodes. The model was prepared in the same was as Model No. 1.

The compacted soil was prepared for treatment by installing the electrodes as shown in Figure 25. The anode was installed by cutting a two-inch wide trench, 6 inches deep and 20 inches long parallel to the short side of the model. The anode was a 20" x 3/8" U-shaped steel bar which was placed in the trench. The trench was then filled with coarse sand to a depth of five inches. Three negative electrodes were used in this model. The cathodes were 3/8" steel bars with sharpened ends. They were driven into the compacted soil to a depth of 6 inches. The location of the cathodes was parallel to the short side of the model and



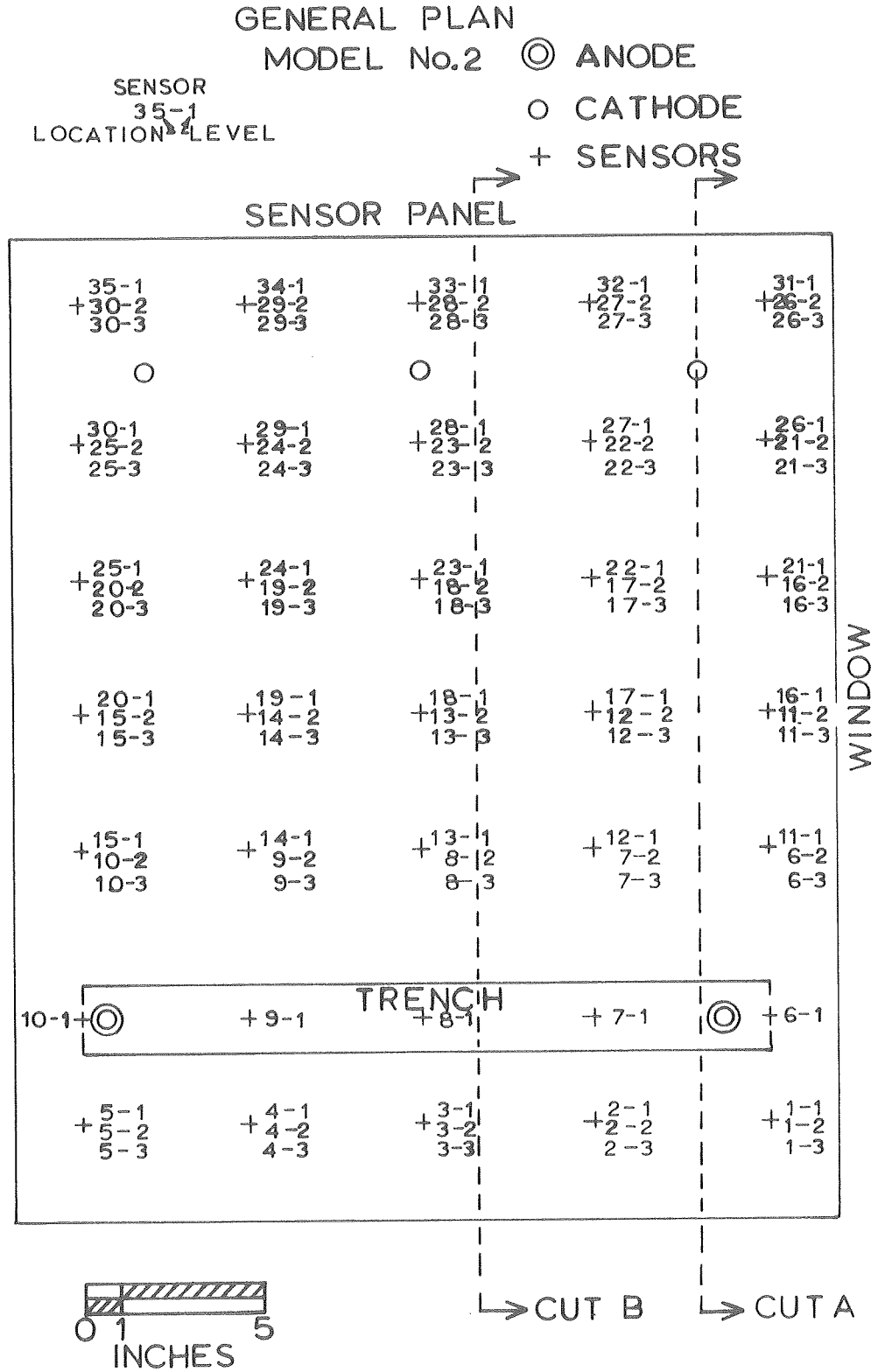


Figure 25

approximately 20 inches from the anode. After the installation of the electrodes, the model was completed in the same manner as Model No. 1.

OPERATION

The operation of both models was essentially the same. After they had been assembled, the chemical solution was supplied to the anodes, keeping the well or trench full at all times. This continued until the demand for solution decreased. At this point, the electro-osmotic treatment was started and allowed to continue until the chemical solution reached the cathodes. During the electro-osmotic treatment, each sensor was read periodically until the peak resistance had been passed. This peaking of the resistance and its subsequent reduction in value was used as an indication that the front had reached the individual sensors. These sensor readings were recorded for over 100 hours in each model study.

RESULTS

Model One. The resistance values for each sensor were plotted as a function of time. These plots are shown in Appendix C. From this data, a contour map of the location of solution front as a function of time is shown in Figures 26 through 28. It is apparent from these figures that the migration of solution is relatively uniform with the flow becoming more rectangular with depth from the surface of the model.

After the solution had reached the cathode, the current was shut off and the model was disassembled. In order to determine the total area covered, several vertical cuts were made and 39 moisture content samples were taken. The location and values for these samples can be seen in Figures 29, 30, and 31.

SOLUTION FRONT VS. TIME

MODEL No. 1
LEVEL 1
9 IN BELOW SURFACE

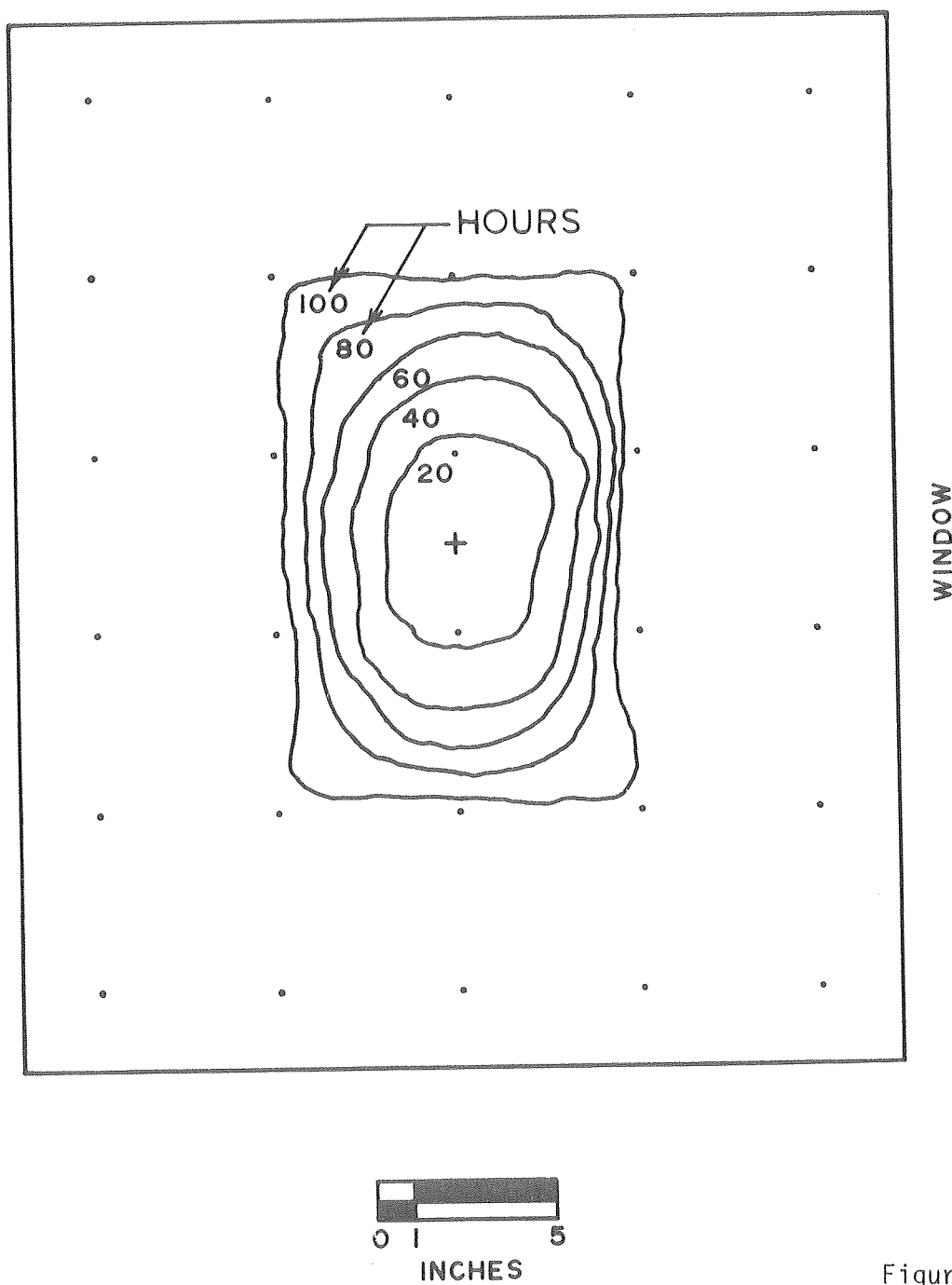


Figure 26

SOLUTION FRONT VS. TIME

MODEL No. 1
LEVEL 2
6 IN BELOW SURFACE

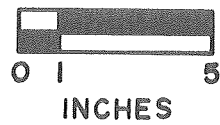
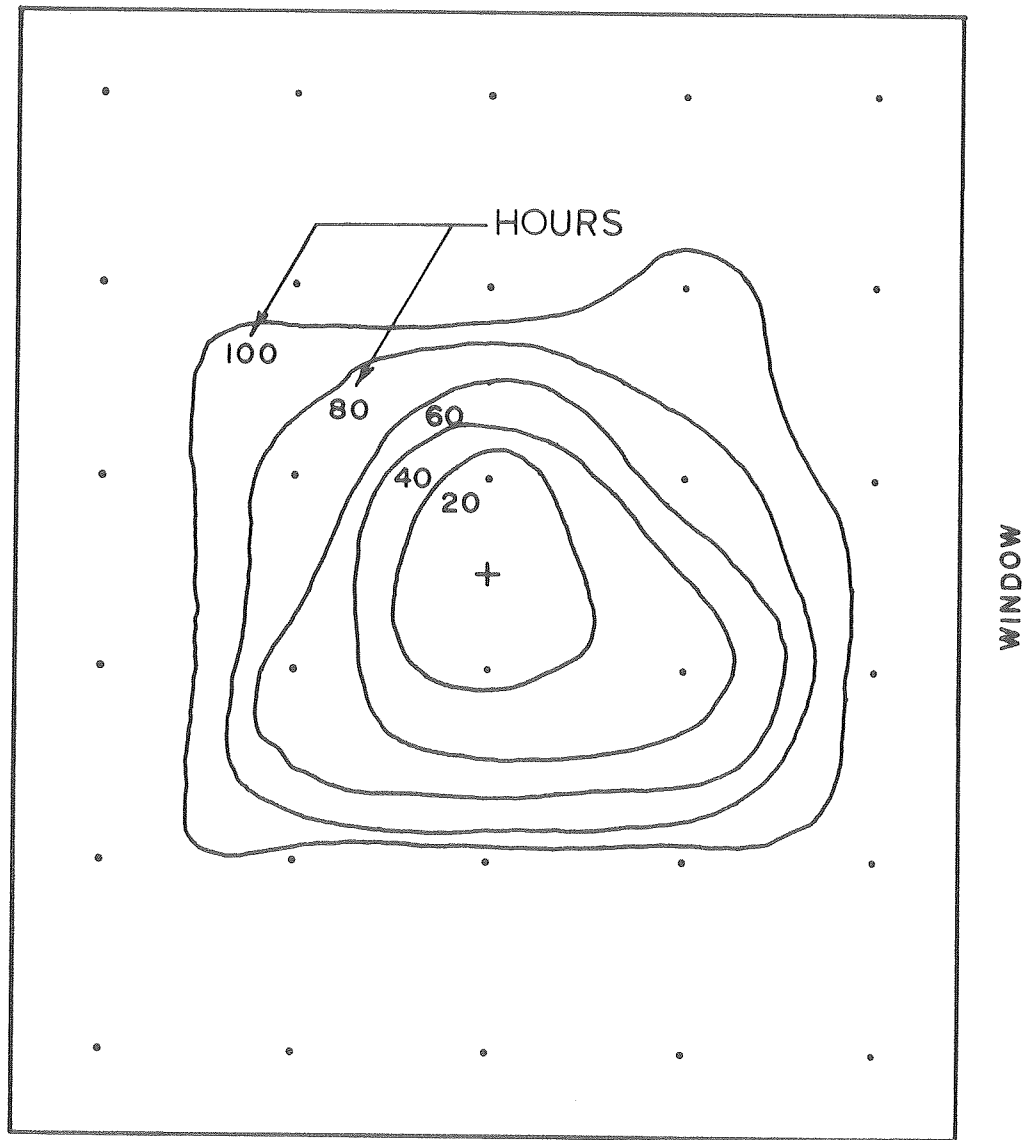


Figure 27

SOLUTION FRONT VS. TIME

MODEL No.1
LEVEL 3
3 IN BELOW SURFACE

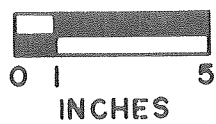
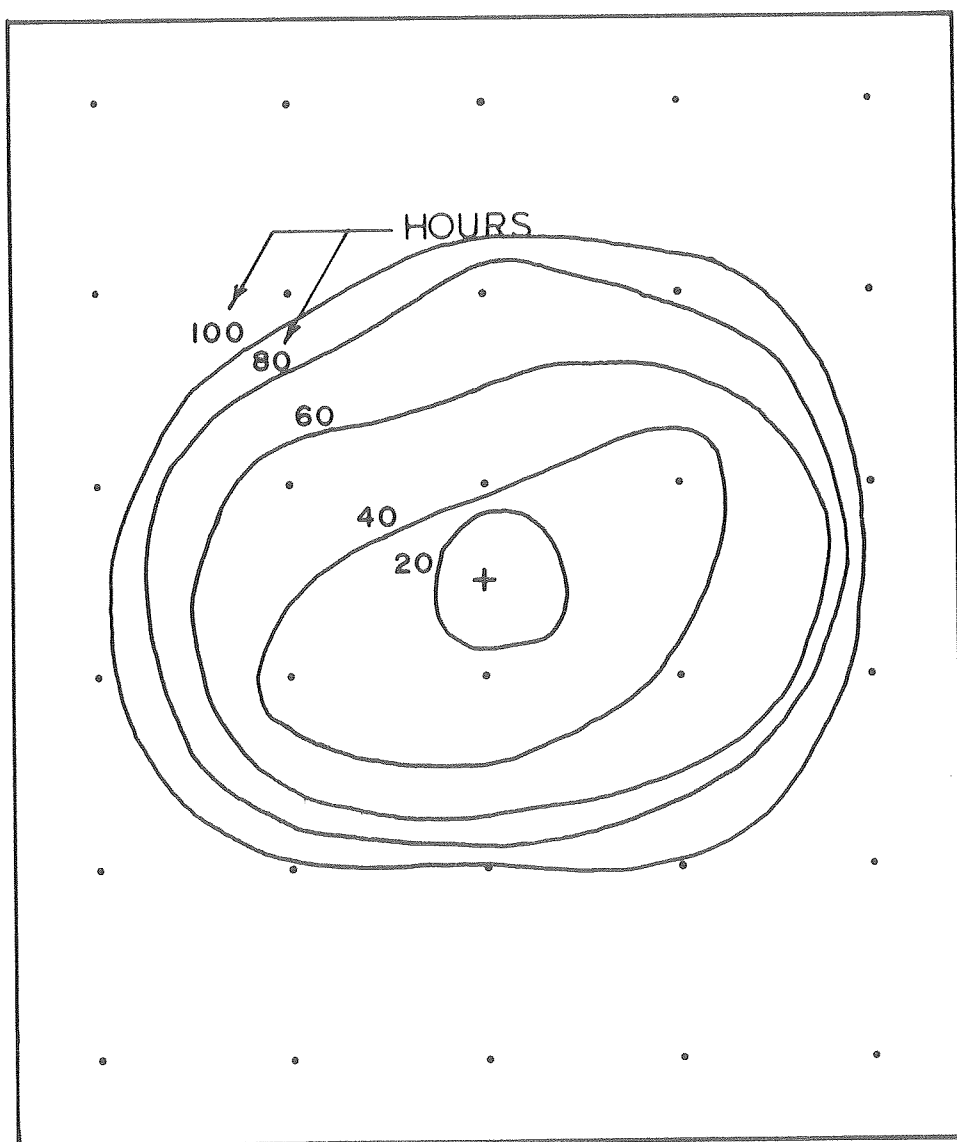


Figure 28

MOISTURE CONTENT IN PERCENT
MODEL No.1

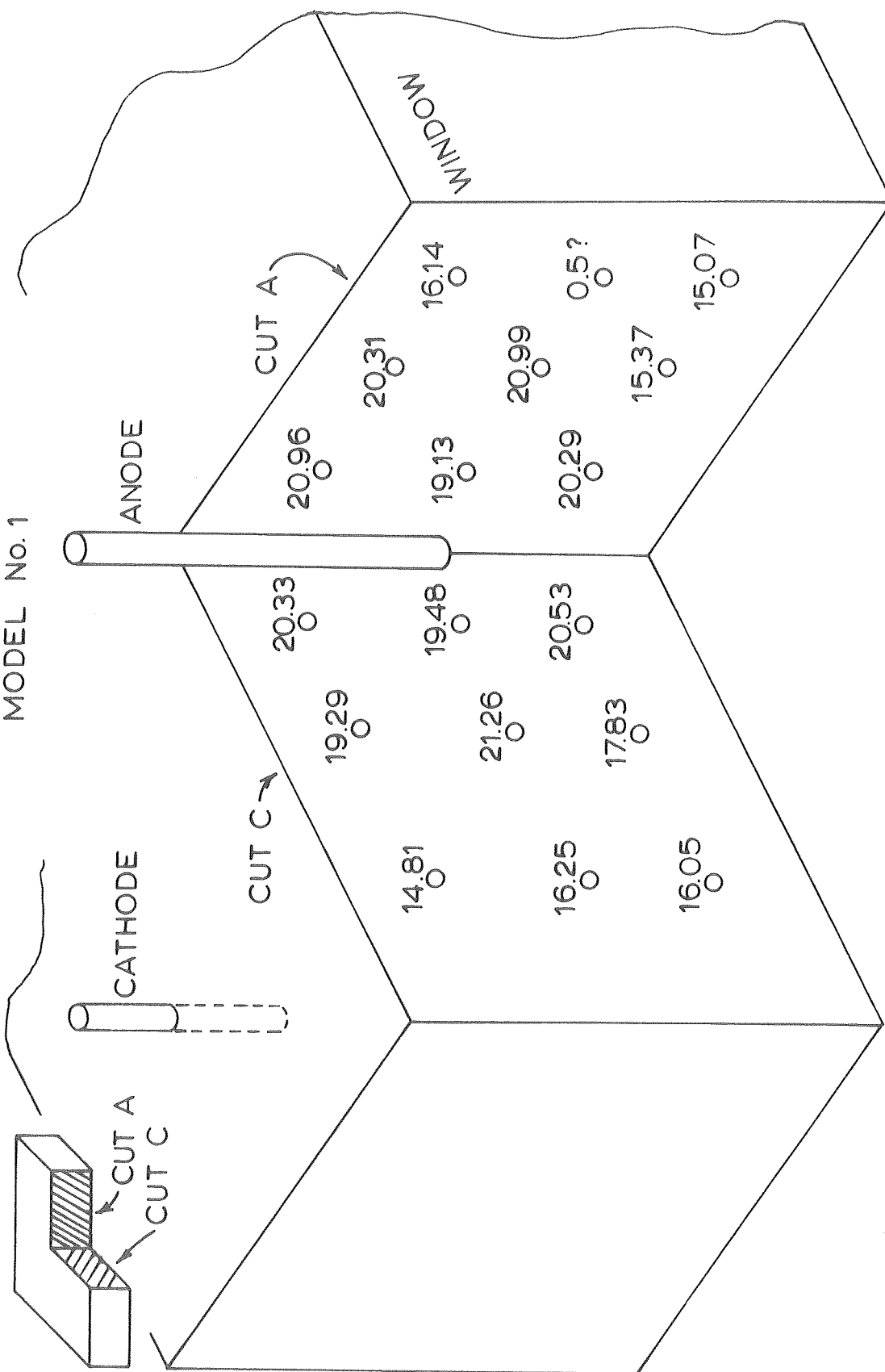


Figure 29

MOISTURE CONTENT IN PERCENT
MODEL No.1

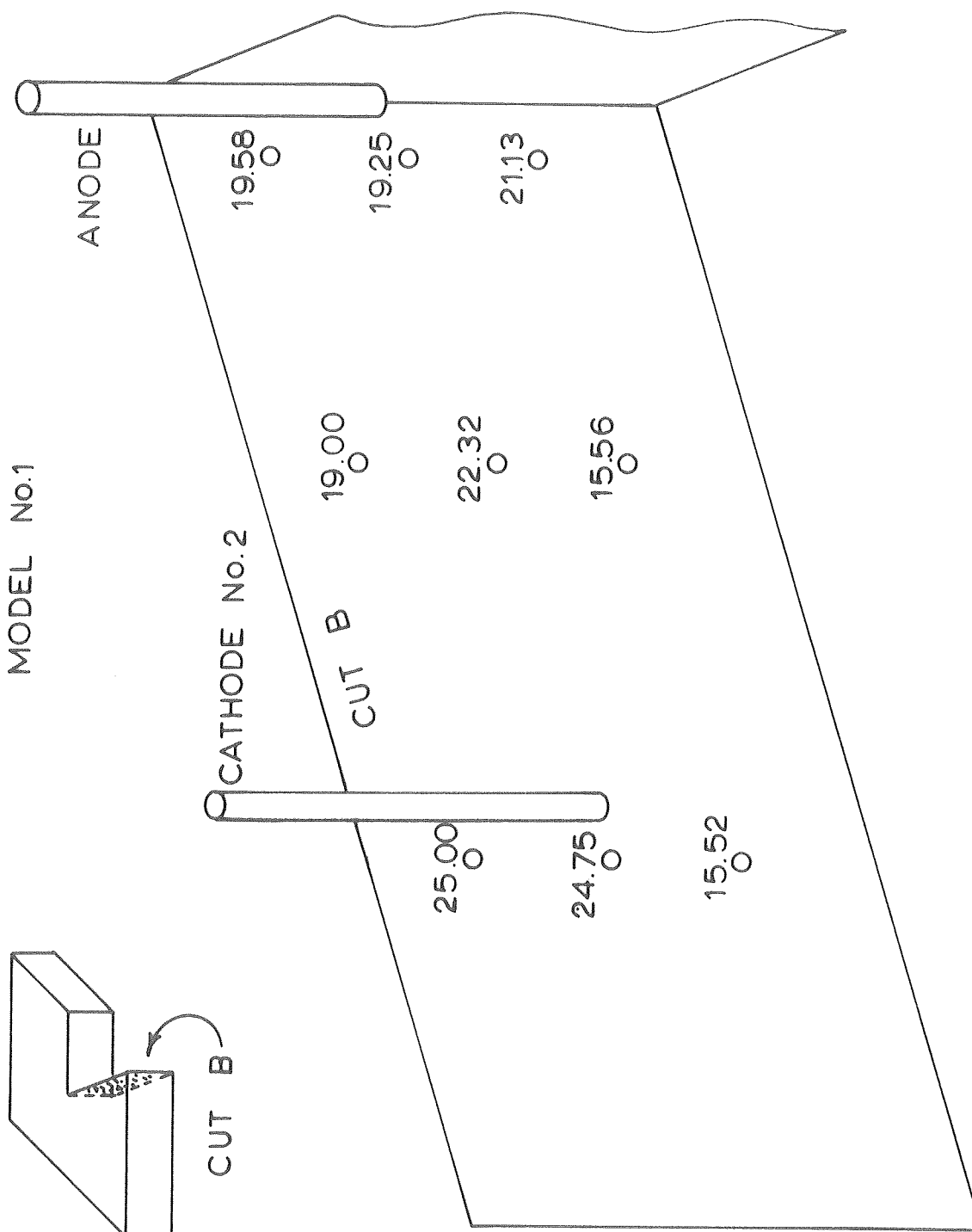


Figure 30

MOISTURE CONTENT IN PERCENT
MODEL No.1

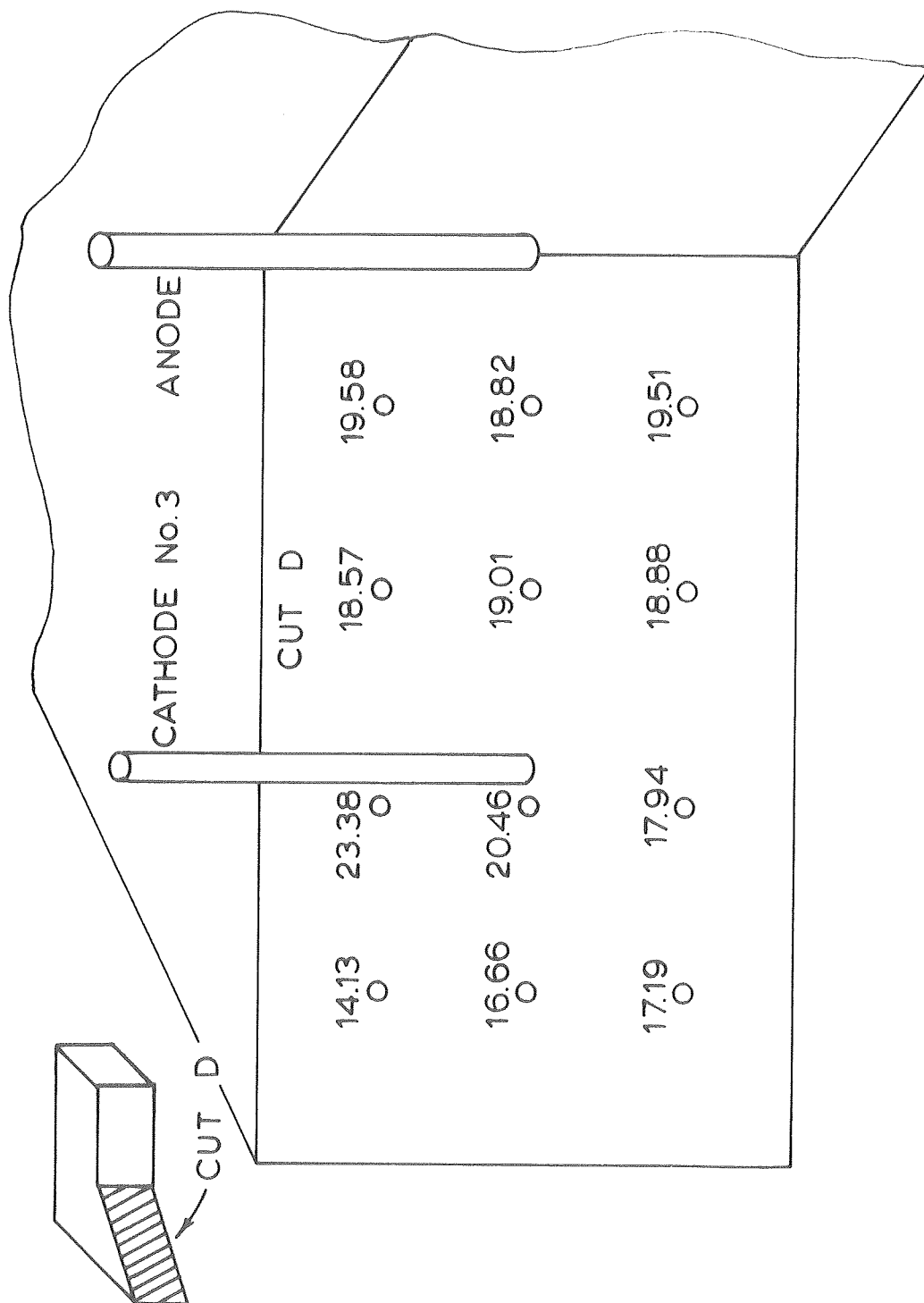


Figure 31

The moisture content samples show good correlation with the solution front indicated by the moisture sensors. It is interesting to note that the moisture increased on the side of the cathode opposite the side facing the anode. Using visual observation of the solution front seen in the cuts, the locations and results of expansive pressure samples can be seen in Figure 32. The results of the expansive pressure tests can also be seen in Table 4. As indicated in Figure 33, the reduction in expansive pressure decreases fairly rapidly with increasing distance from the anode. Since the moisture content samples indicated that the solution front had moved to at least the cathodes, the results of the expansive pressure test indicate that KCl had been removed from the solution. Thus, in the second model, it was decided to allow the current to remain on after the solution had reached the cathodes. This was done in order to determine if the KCl would decrease the expansive pressures over a larger area.

Model Two. As in Model No. 1, the resistance values for each sensor were plotted as a function of time. These data are shown in Appendix C. From these results, a contour map of the location of the solution front plotted as a function of time is shown in Figures 34 through 36.

It is apparent from these figures that the migration of solution is relatively uniform. In addition, the area covered in Model No. 2 is greater than the area in Model No. 1. In this model, the area of treatment was also greater near the surface, and the treated area decreased with depth. This was found to be the same as Model No. 1.

EXPANSIVE PRESSURE IN lbs/ft²
MODEL No.1

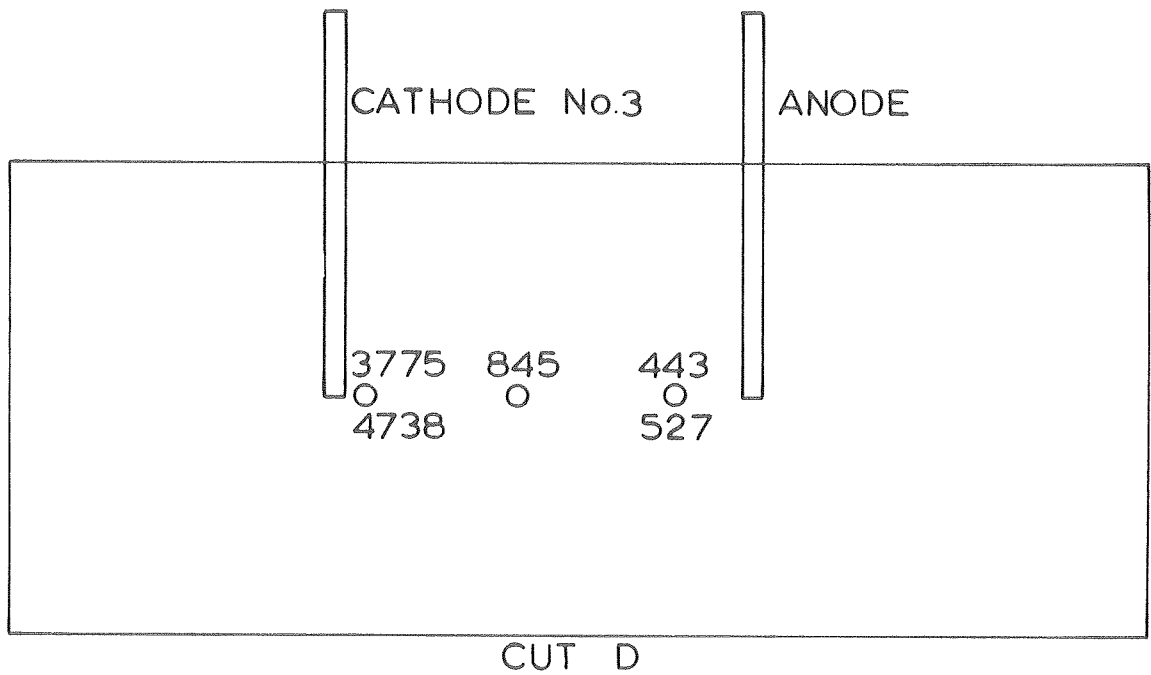
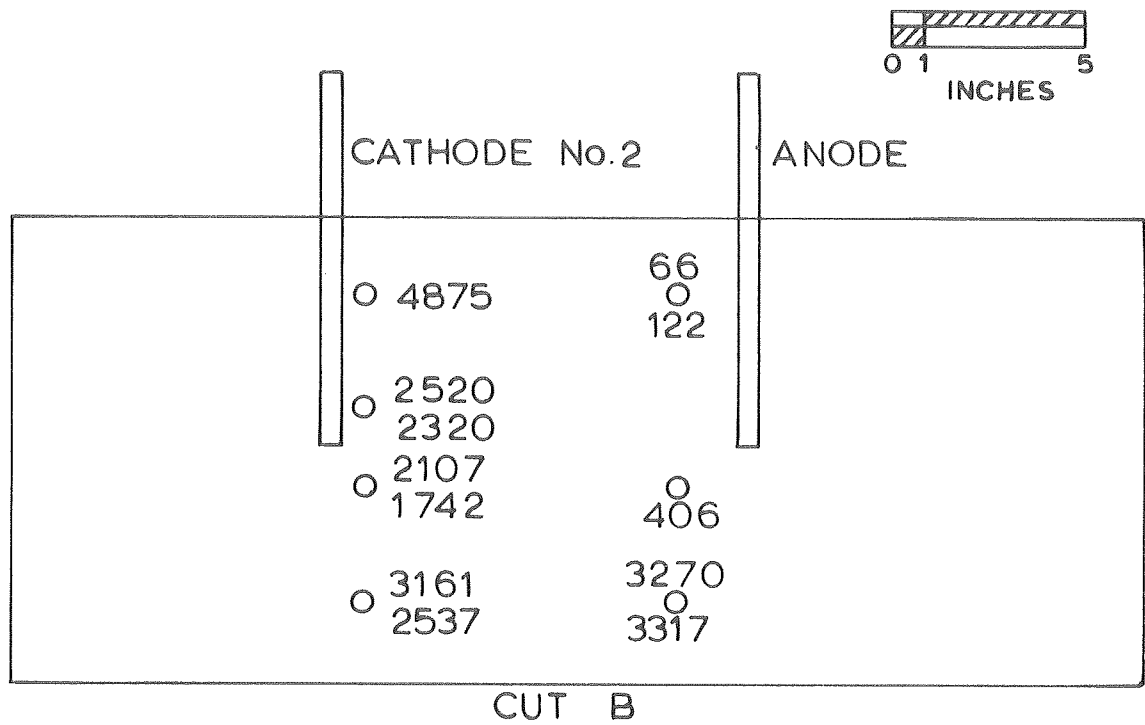


Figure 32

Table 4
MODEL NO. 1
EXPANSIVE PRESSURES AND REDUCTION FACTORS

| <u>Sample Number*</u> | <u>Expansive Pressure #/ft²</u> | <u>Reduction Factor</u> |
|-----------------------|--|-------------------------|
| Untreated | 5000 | 1.00 |
| B-1A | 4875 | 1.03 |
| B-2A | 2520 | 1.98 |
| B-2B | 2320 | 2.16 |
| Average | 2420 | 2.07 |
| B-3A | 2107 | 2.37 |
| B-3B | 1742 | 2.87 |
| Average | 1924 | 2.60 |
| B-4A | 3161 | 1.58 |
| B-4B | 2537 | 1.97 |
| Average | 2849 | 1.76 |
| B-5A | 66 | 75.76 |
| B-5B | 122 | 40.98 |
| Average | 94 | 53.19 |
| B-6A | 406 | 12.32 |
| B-7A | 3770 | 1.33 |
| B-7B | 3317 | 1.51 |
| Average | 3543 | 1.41 |
| D-1A | 3775 | 1.32 |
| D-1B | 4738 | 1.06 |
| Average | 4256 | 1.17 |
| D-2A | 845 | 5.92 |
| D-3A | 443 | 11.29 |
| D-3B | 527 | 9.49 |
| Average | 485 | 10.31 |

*See Figure 32 for location.

EXPANSIVE PRESSURE VS DISTANCE FROM ANODE

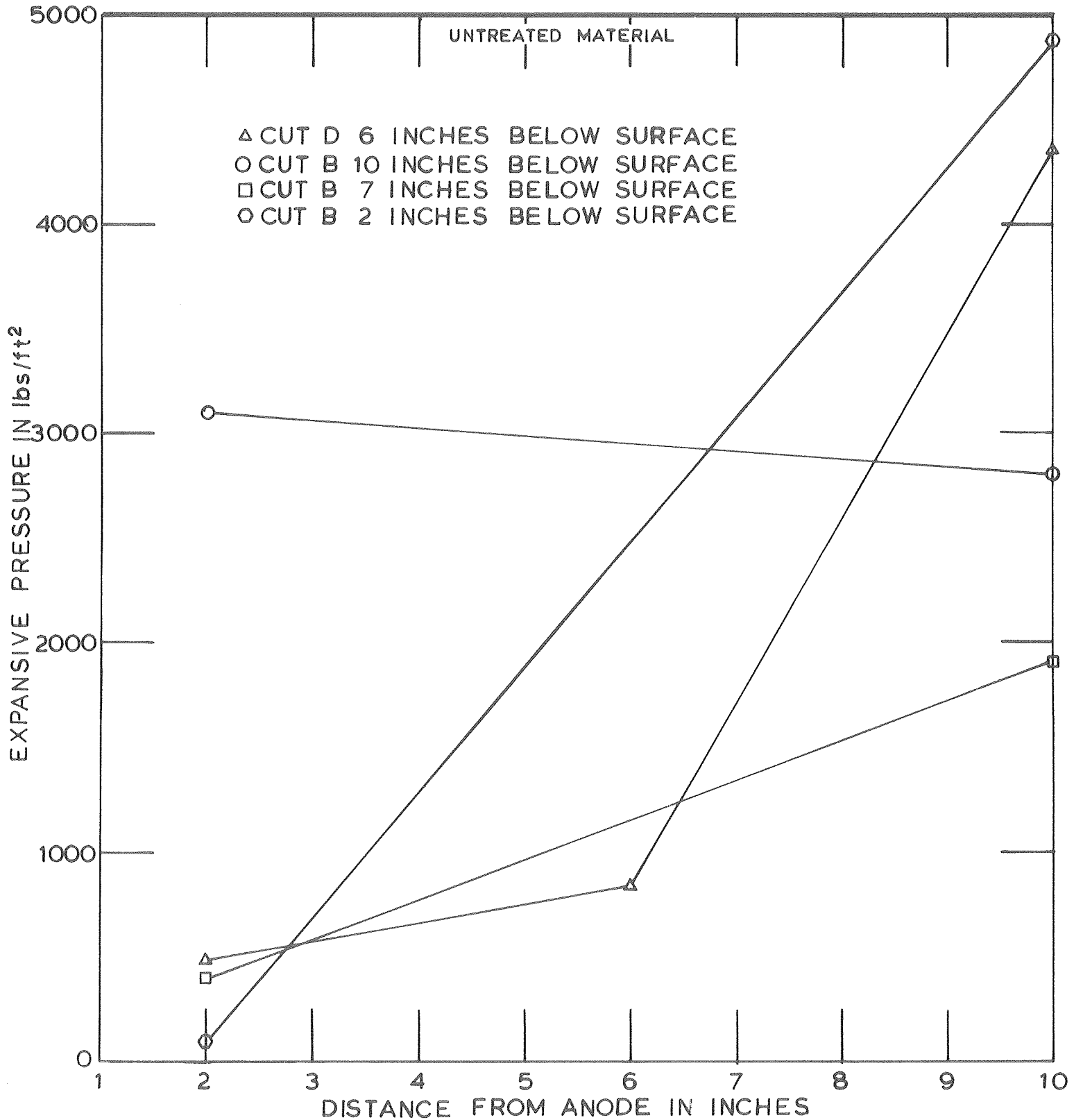


Figure 33

SOLUTION FRONT VS. TIME

MODEL No. 2
LEVEL 1
9" BELOW SURFACE

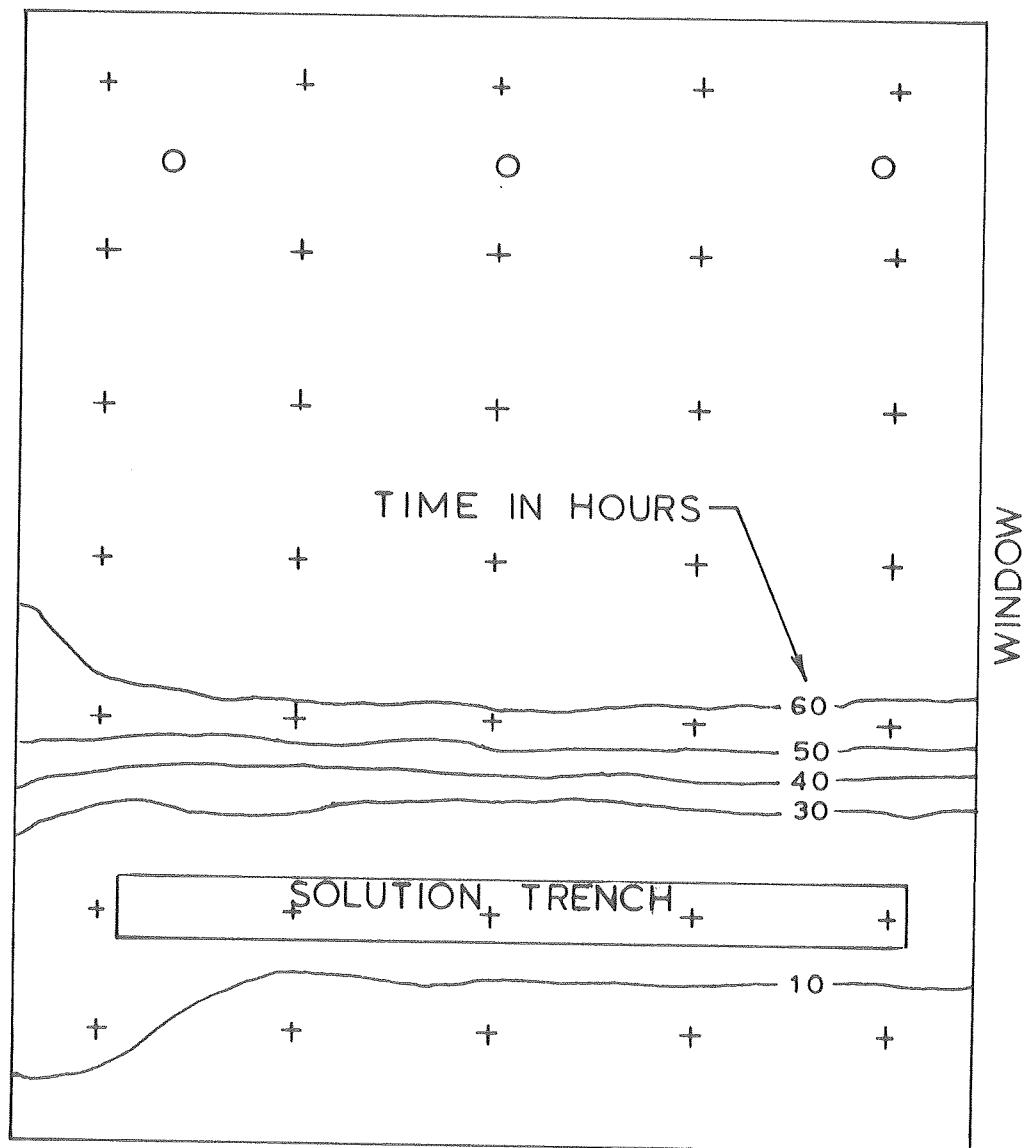


Figure 34

SOLUTION FRONT VS. TIME

MODEL No. 2

LEVEL 2

6" BELOW SURFACE

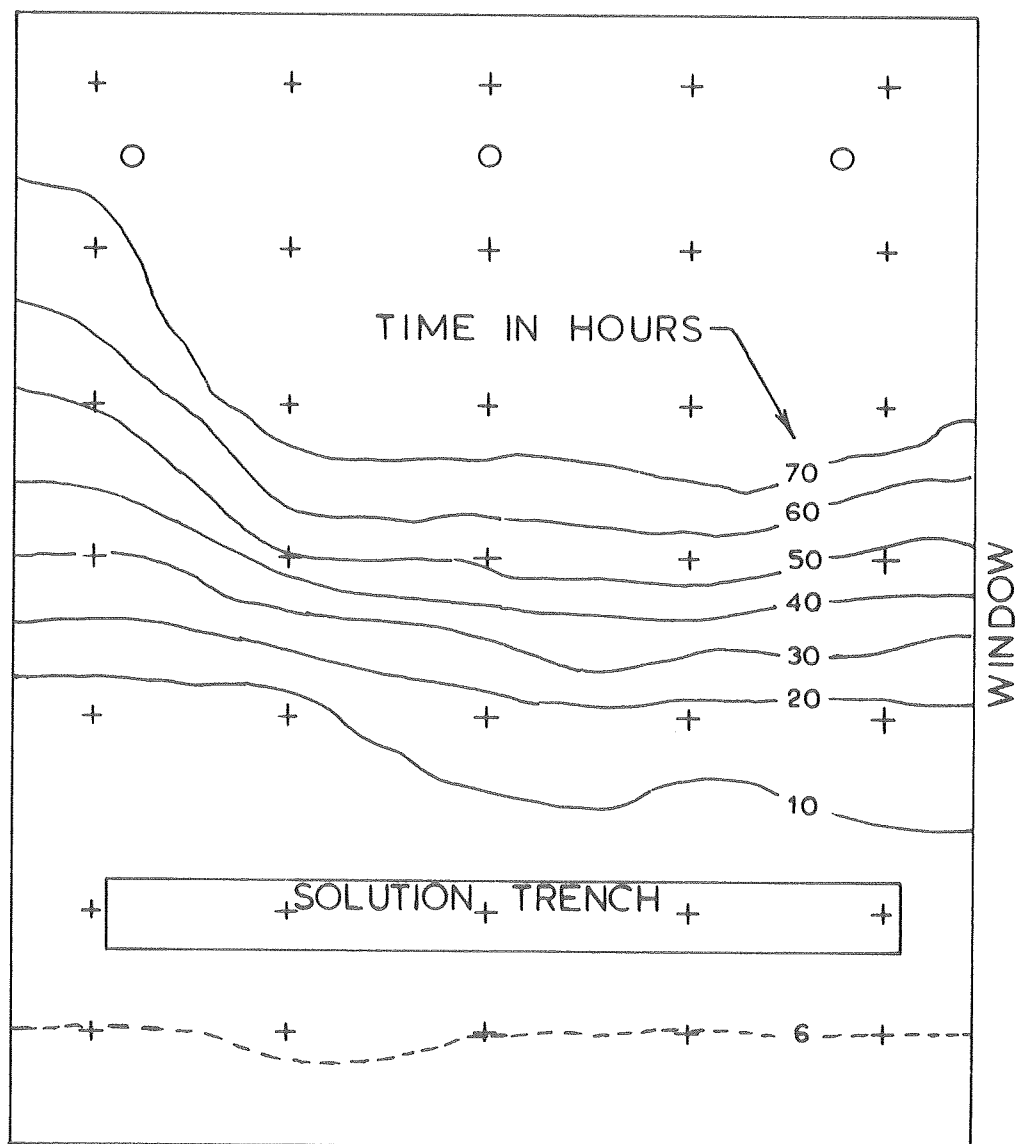


Figure 35

SOLUTION FRONT VS. TIME

MODEL No. 2

LEVEL 3

3" BELOW SURFACE

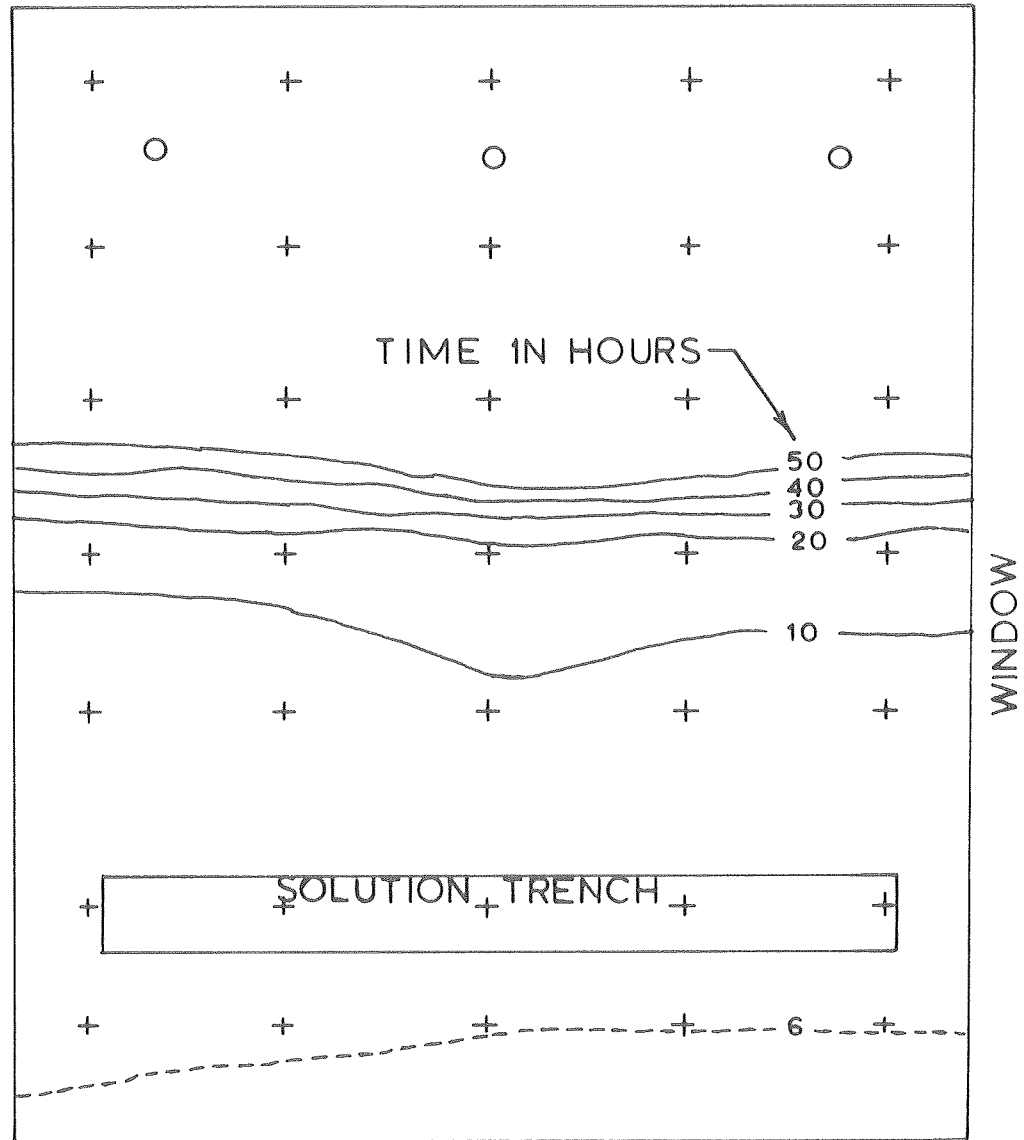


Figure 36

Instead of stopping the electro-osmotic treatment immediately after the solution reached the cathode, it was allowed to run for an additional 30 hours. One of the difficulties encountered in this model occurred just prior to the solution reaching the cathode; solution was observed leaking from the model at one of the corners. Since it was feared that this might affect the results, all sampling was done on the opposite side of the model. However, the effect of leakage on the overall performance of this model could not be determined.

After the completion of the test, two cuts, one four inches from the window and the other 11 inches from the window, were made perpendicular to the electrodes. The locations and results of the moisture content samples can be seen in Figure 37. The expansive pressure samples can be seen in Figure 38. The moisture contents indicate a fairly uniform coverage of the model by the chemical solution. Expansive pressure vs. distance from anode are plotted in Figures 39 and 40. These plots indicate that the expansive pressure still increases with distance from the anode; however, as can be seen in Table 5, the reduction of the expansive pressure near the cathode is greater than for Model No. 1.

CONCLUSIONS

In any discussion of model testing, one should point out some of the inherent difficulties involved. First, the problem of attempting to model like parameters that exist in the field to the laboratory is enormous. Problems consist of size, orientation of grains, side effects, boundary conditions, and many more.

MOISTURE CONTENT IN PERCENT
MODEL No. 2

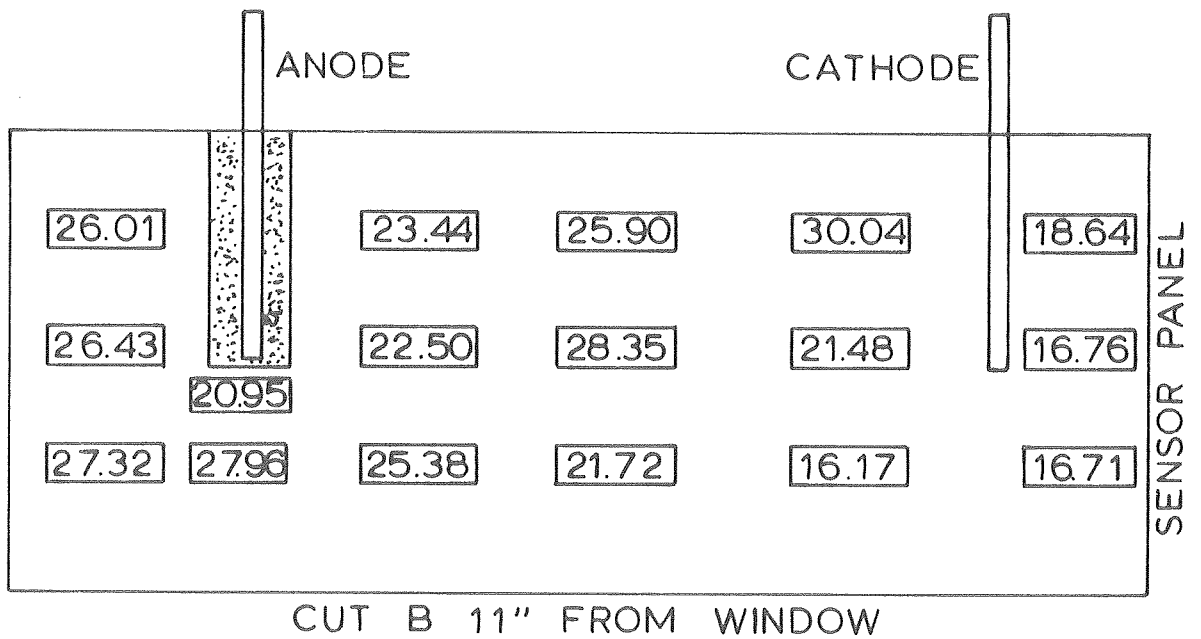
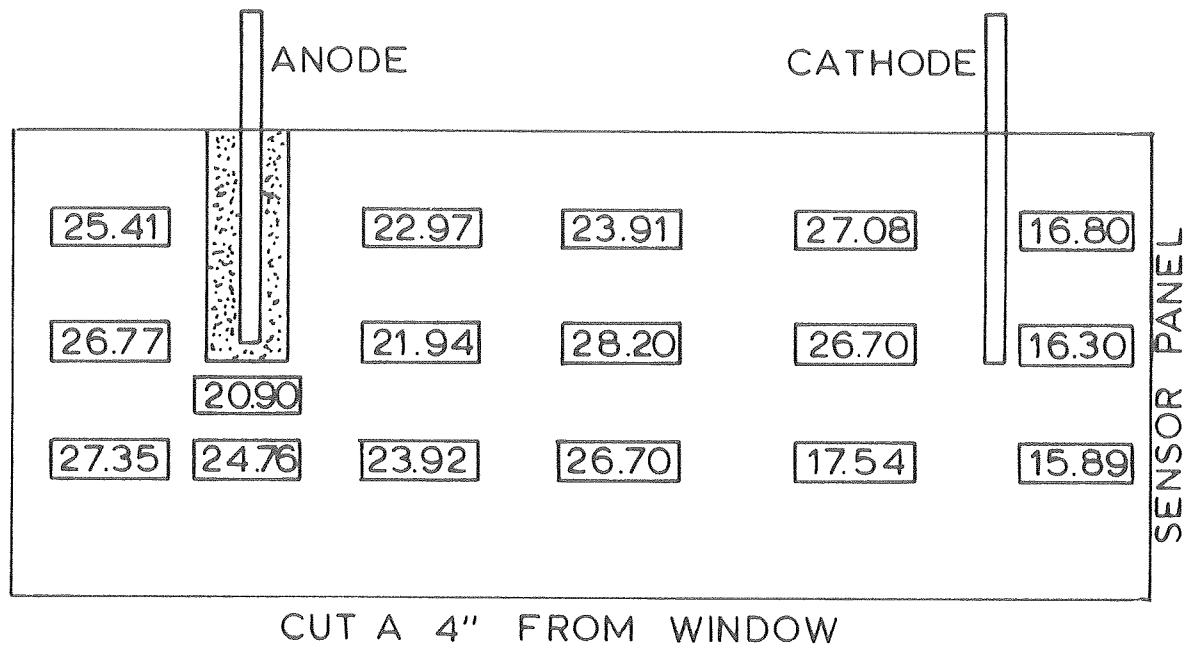


Figure 37

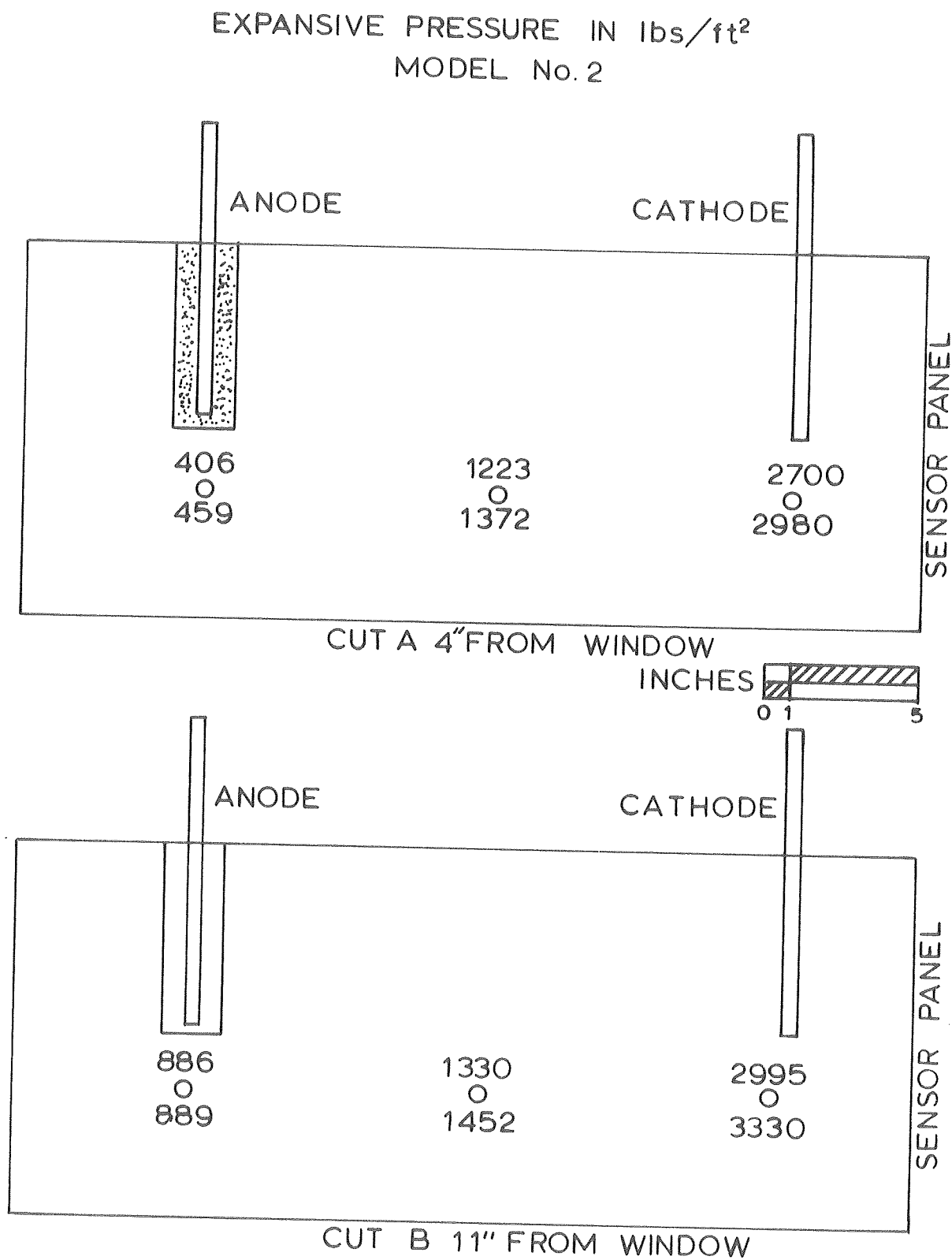


Figure 38

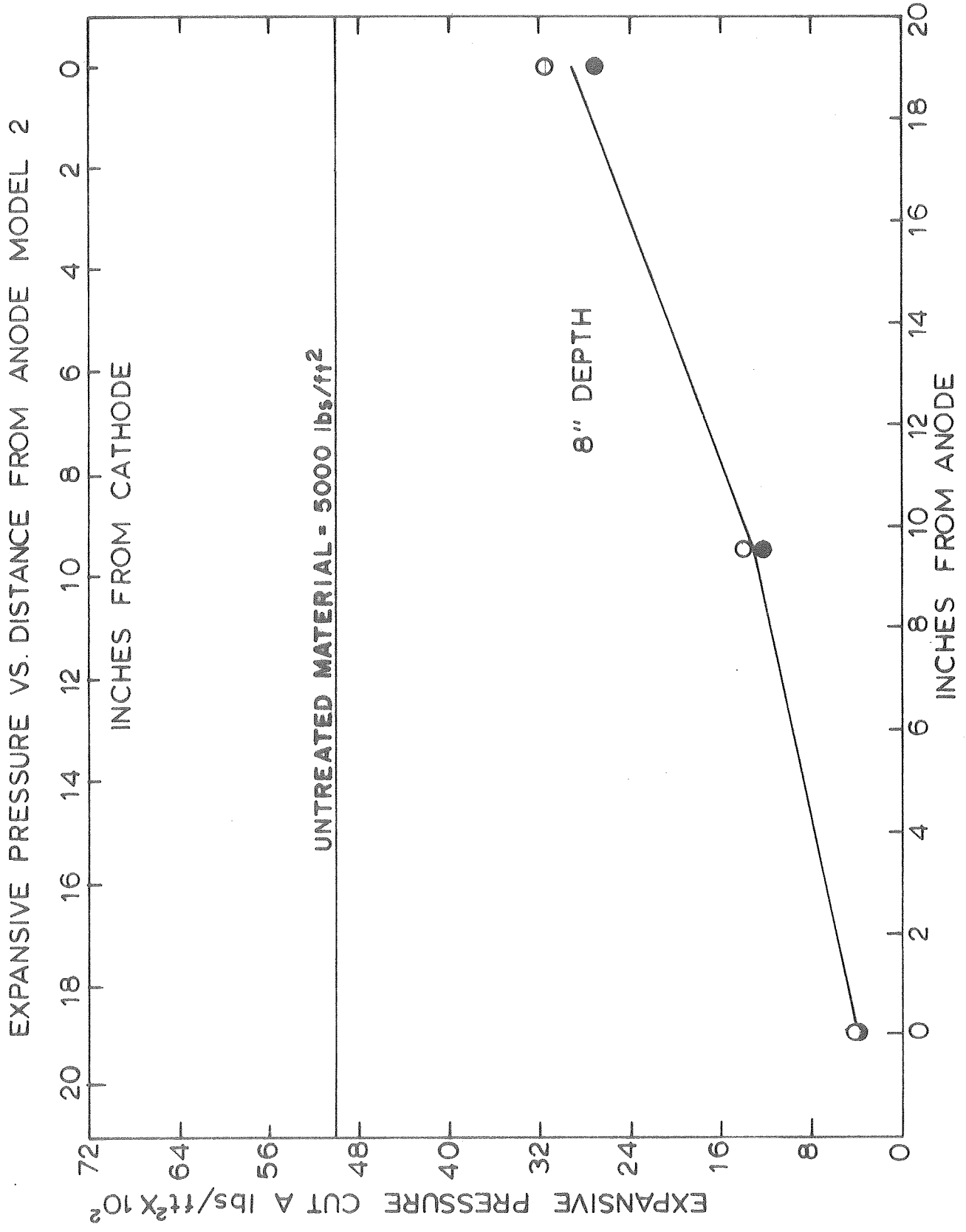


Figure 39

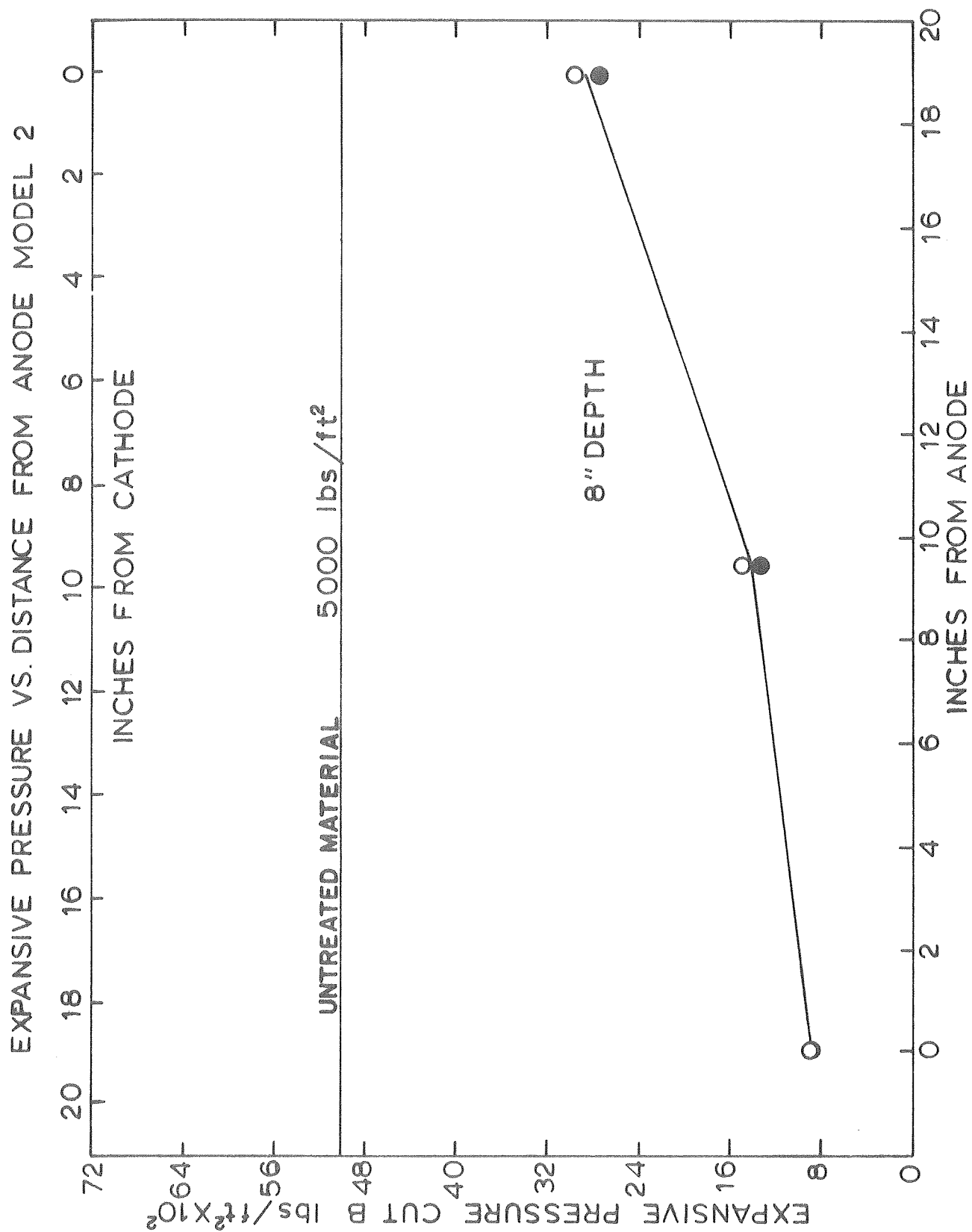


Figure 40

Table 5
MODEL NO. 2
EXPANSIVE PRESSURES AND REDUCTION FACTORS

| <u>Sample Number*</u> | <u>Expansive Pressure #/ft²</u> | <u>Reduction Factor</u> |
|-----------------------|--|-------------------------|
| Untreated | 5000 | 1.00 |
| A-1A | 406 | 12.32 |
| A-1B | 459 | 10.89 |
| Average | 432 | 11.56 |
| A-2A | 1223 | 4.09 |
| A-2B | 1372 | 3.64 |
| Average | 1297 | 3.85 |
| A-3A | 2700 | 1.85 |
| A-3B | 2980 | 1.68 |
| Average | 2840 | 1.76 |
| B-1A | 886 | 5.64 |
| B-1B | 889 | 5.62 |
| Average | 888 | 5.63 |
| B-2A | 1330 | 3.76 |
| B-2B | 1452 | 3.44 |
| Average | 1391 | 3.59 |
| B-3A | 2995 | 1.67 |
| B-3B | 3330 | 1.50 |
| Average | 3162 | 1.58 |

*See Figure 38 for location.

It is difficult to reproduce the field conditions in the laboratory. Therefore, based on the model studies, it is impossible to determine which configuration of electrodes would produce better results in the field. From the model studies, it appears that both arrangements give fairly uniform coverage of the area under treatment. However, it is impossible to determine the velocity of the solution front in general terms because of the previously mentioned boundary conditions and this parameter must be determined in actual field measurements.

These model studies did indicate one important factor. Even though solution has reached the cathode, the current should remain on for some additional period of time so that the KCl can cover a larger area.

Chapter 6

SPRING FIELD TEST

The scope of the spring field test was:

1. To choose a test site on old Route 89 where heaving had been observed.
2. To design, install and operate a field test, consisting of different electrode arrangements and methods of adding a Potassium chloride solution to the clay.
3. To sample the treated sections.
4. To test the samples for expansive pressure.
5. To determine the most effective means of field treatment.

SITE SELECTION AND SAMPLING

The field work began in April with the selection of a new test site approximately one mile south of the fall site. The site was located approximately 125 yards east of milepost 488 on an unmaintained section of old Route 89. Two 20' x 20' sections and one 10' x 20' section of the two-lane highway were selected. The sections were approximately 100 feet apart. Using a hand auger, samples were taken from the center of each section. However, due to the limitations of the equipment, only one composite sample from 0' to 3' was taken from each section. This proved to be inadequate and it is suggested that in future test sections, extensive pre-test sampling should be performed.

FIELD TEST

Design. It was decided to try three different test site arrangements. Site one employed horizontal electrodes and used solution wells; site two used horizontal electrodes and the base course was flooded as a means of introducing the chemical solution into the subgrade; site three used horizontal electrodes and a central trench cut 18 inches into the existing subgrade. By filling the trench just to the top with chemical solution, a direct comparison could be made to that of flooding the base course. These sites will be discussed in greater detail later in this chapter.

The solution for the three sites was the same and was supplied from a common source. In an attempt to decrease the amount of chemical required to stabilize a given site, it was decided to use a 4% solution of KCl. However, in order to obtain coverage of a larger area, the chemical solution was supplied to each site for ten to fifteen days before the start of electro-osmotic treatment.

Because the expansive pressure was approximately one-fourth that of the previous test it was determined on the basis of expected solution consumption that a four percent solution would be adequate. While this solution was adequate for the upper material which had been previously sampled, it was inadequate for the material below a depth of three feet. In the future it is suggested that, in addition to greater preliminary sampling, a graph of expansive pressure vs. percent KCl as seen in Figure 4 be made. This would give the optimum KCl needed for the area to be treated.

As a result of the fall field test, it was decided to use the wetting agent C-61 to increase the rate of penetration of the KCl solution. Approximately 0.5 percent of C-61 by weight of water was used.

Site One. A cross-section and plan view of the site can be seen in Figure 41. Site one consists of a 10' x 20' section at the southernmost end of the test area. The cathode was a number 4 rebar placed horizontally with a vertical extension sticking out of the ground to which the wires from the central panel were connected. The anode was similar except that it was a number 8 rebar. The larger size was used to allow for the removal of metal during the electro-osmosis process.

The electrodes were placed 18 inches below the base course in trenches. These trenches were then backfilled with clay and compacted to the in-place field density. The solution was added through solution wells on 5-foot centers extending 18 inches into the clay. These solution wells were filled with clean gravel to the bottom of the base course. In an actual field stabilization program these holes would have to have some type of impervious sleeve or pipe from the bottom of the base course to the top of the base course in order to prevent the solution from flooding into the base course.

Site Two. The electrode arrangement in site two was exactly as in site one. The significant difference was in the method of solution application, see Figure 42. In this site the roadbed was divided into four equal parts by three trenches. These trenches were 12 inches wide and extended to a depth of approximately 4 inches. The depth of the trench was determined by the thickness of base material. It was the intent of this site not to have the trenches penetrate the clay but

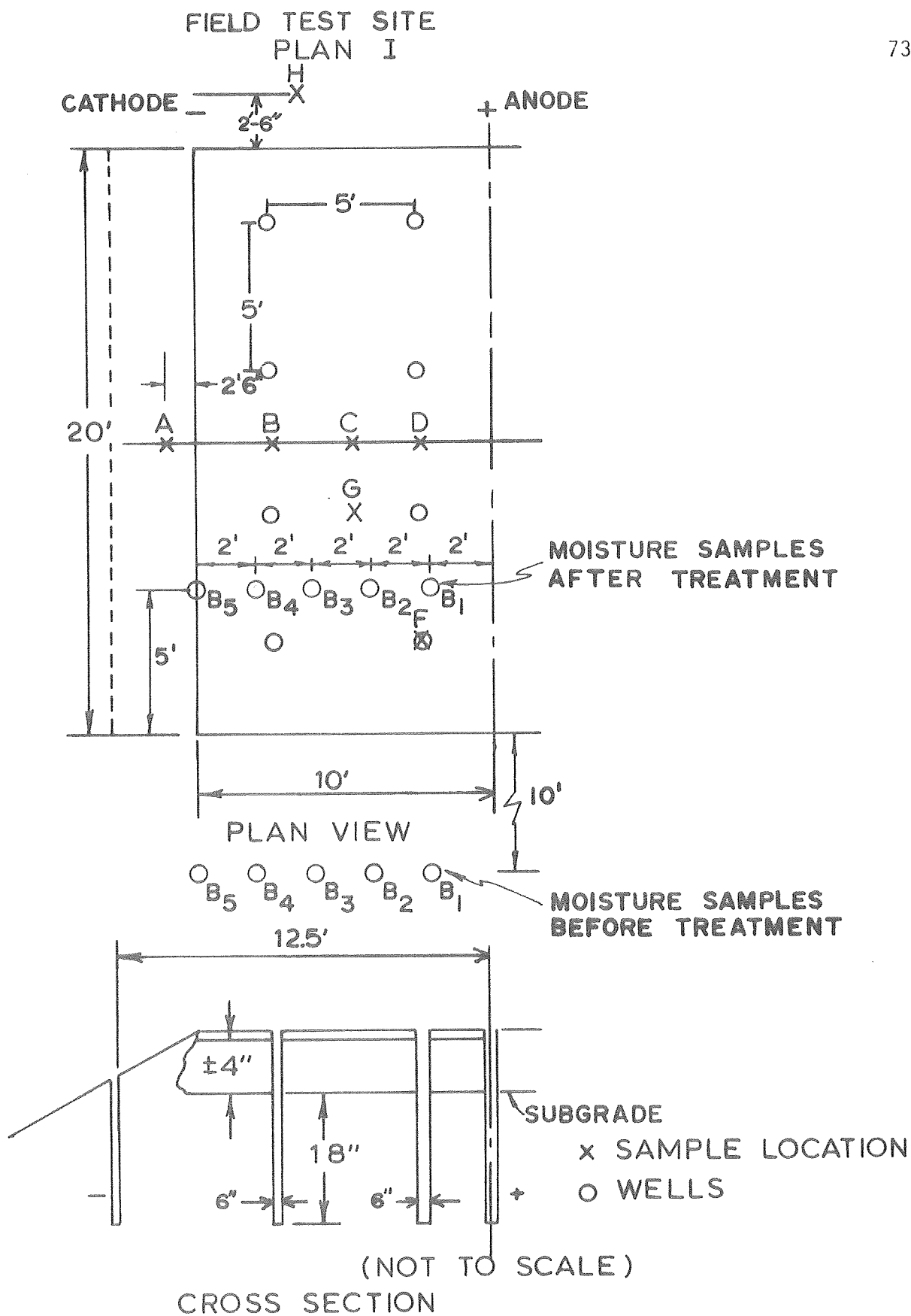


Figure 41

FIELD TEST SITE

PLAN II

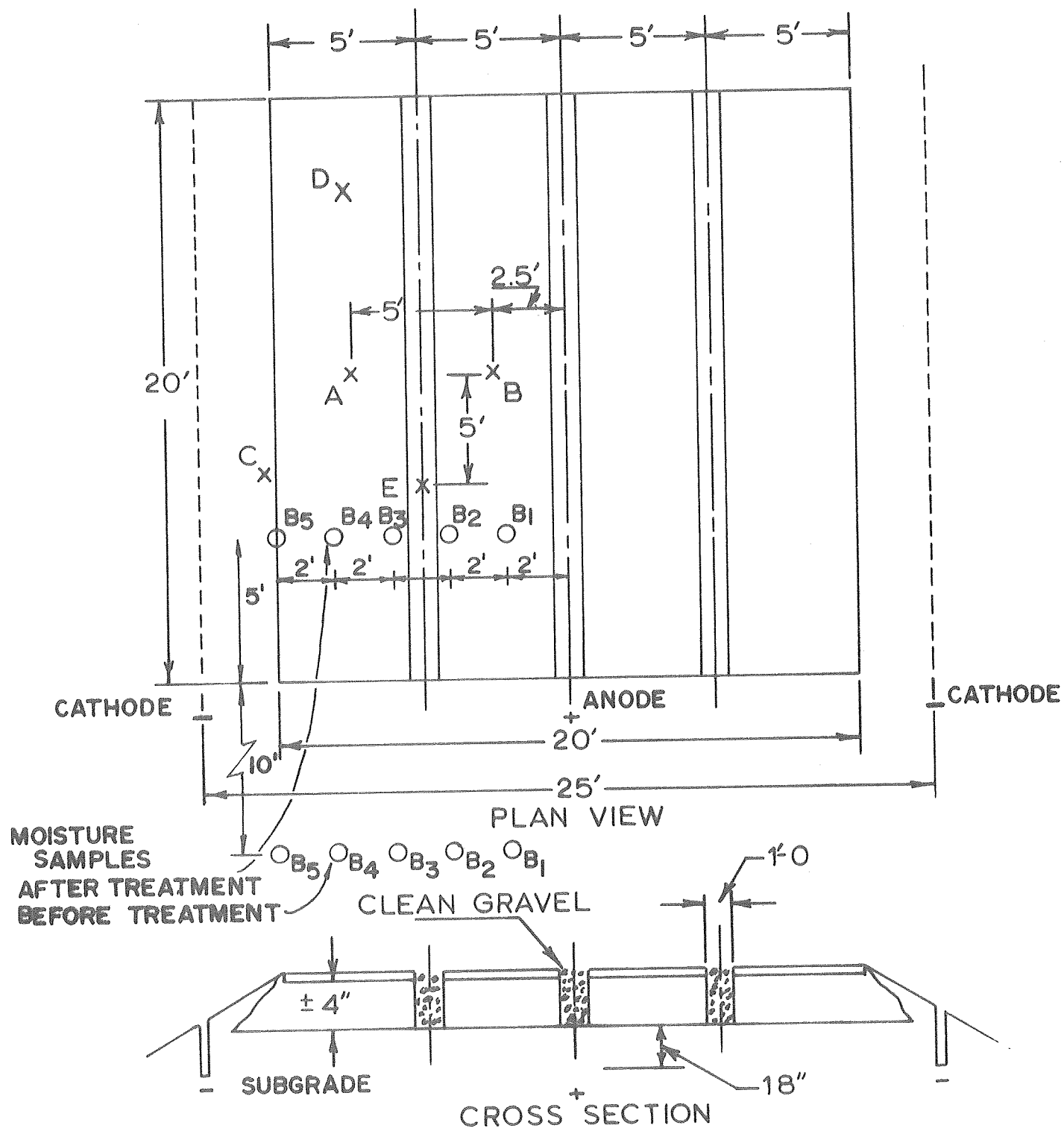


Figure 42

rather just fully penetrate the base material. After digging the trenches they were filled with clean gravel and this filter was used to flood the base course.

Site Three. Site three used the same electrode arrangement as sites one and two; however, in this site the solution was applied through a central trench 12 inches wide and dug eighteen inches into the clay, see Figure 43.

INSTALLATION

The installation of the test site was begun in April under the direction of the Arizona Highway Department. The three sites were set up as indicated. Two large tanks were placed on a small hill adjacent to the central site; one of these contained water to be used to mix the potassium chloride and C-61 solution and the other was used to store this solution. The second tank was heated by a propane torch in order to keep the solution thoroughly mixed. Hoses were used to transfer the solution by gravity from the tanks to the individual sites.

After the sites had been installed and before the wiring was begun, several holes were drilled in each site to a depth of ten feet in order to obtain moisture content samples. These samples were taken for comparison with moisture contents after completion of the test site, see Figures 44 through 46.

On May 12th the generator and control panel used in the fall test were delivered to the site and the wiring initiated. Using number 8 wire all the sites were connected to the control panel, one wire for each electrode. The final connections were completed on the morning of May 15, 1972.

FIELD TEST SITE

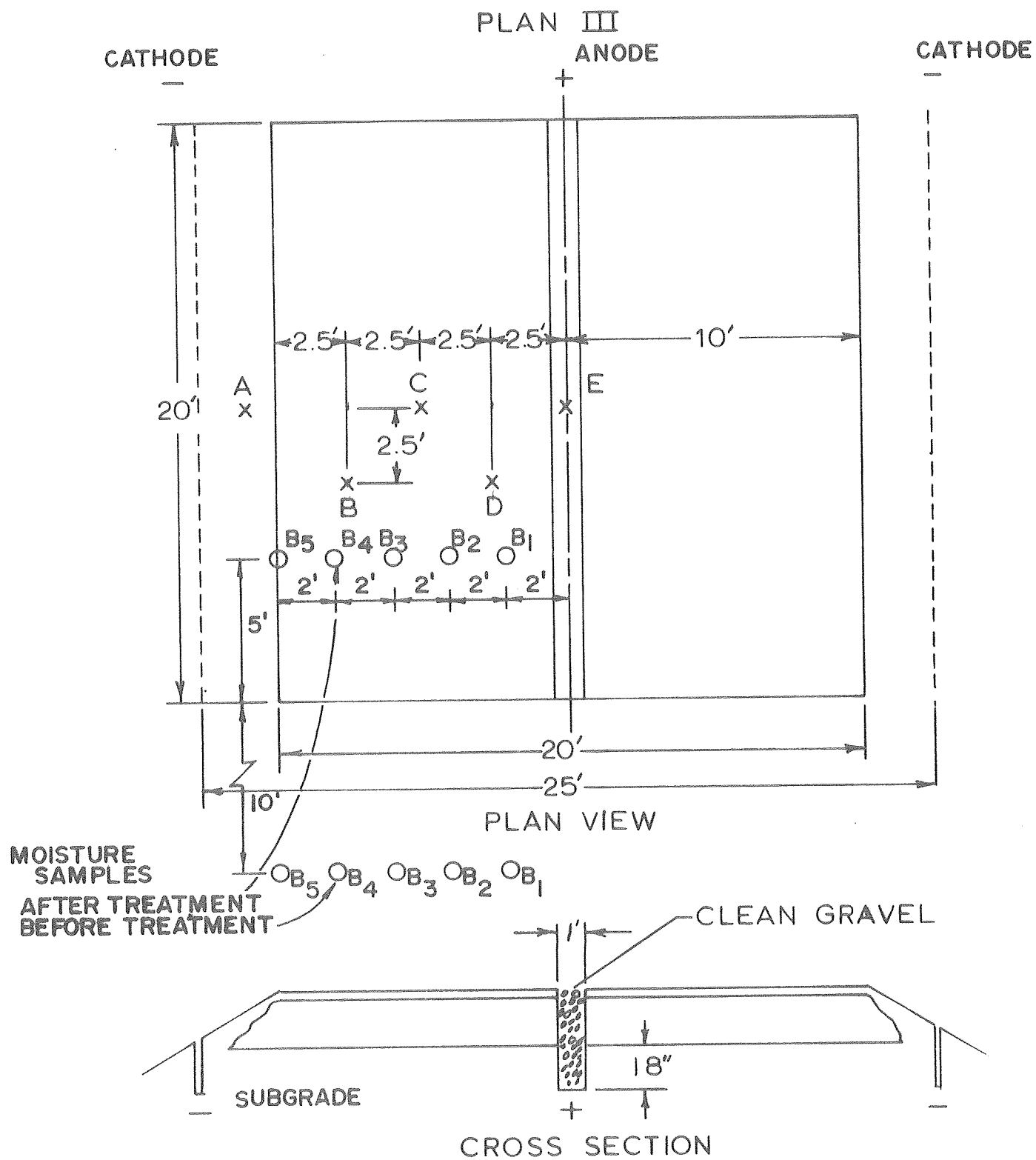


Figure 43

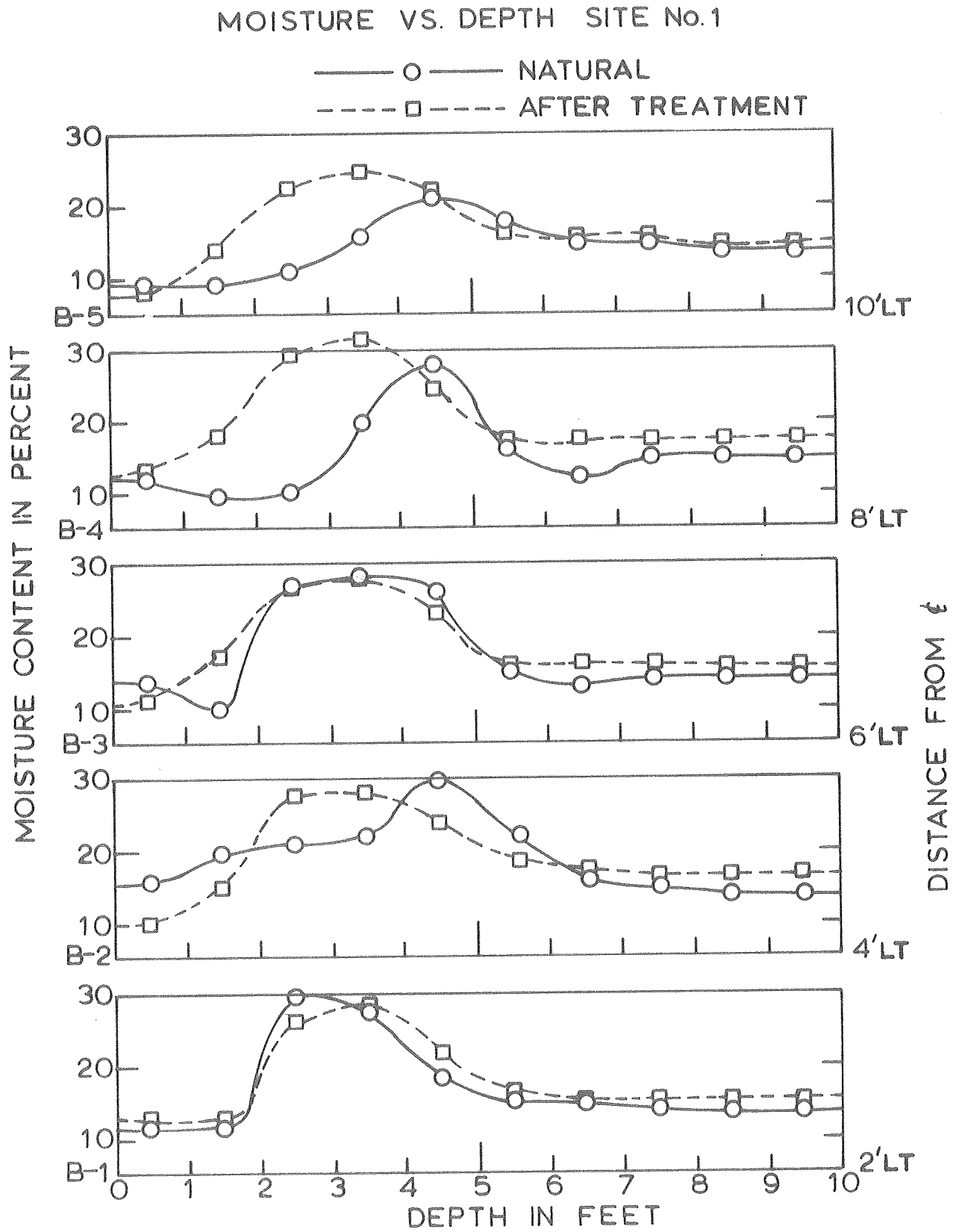


Figure 44

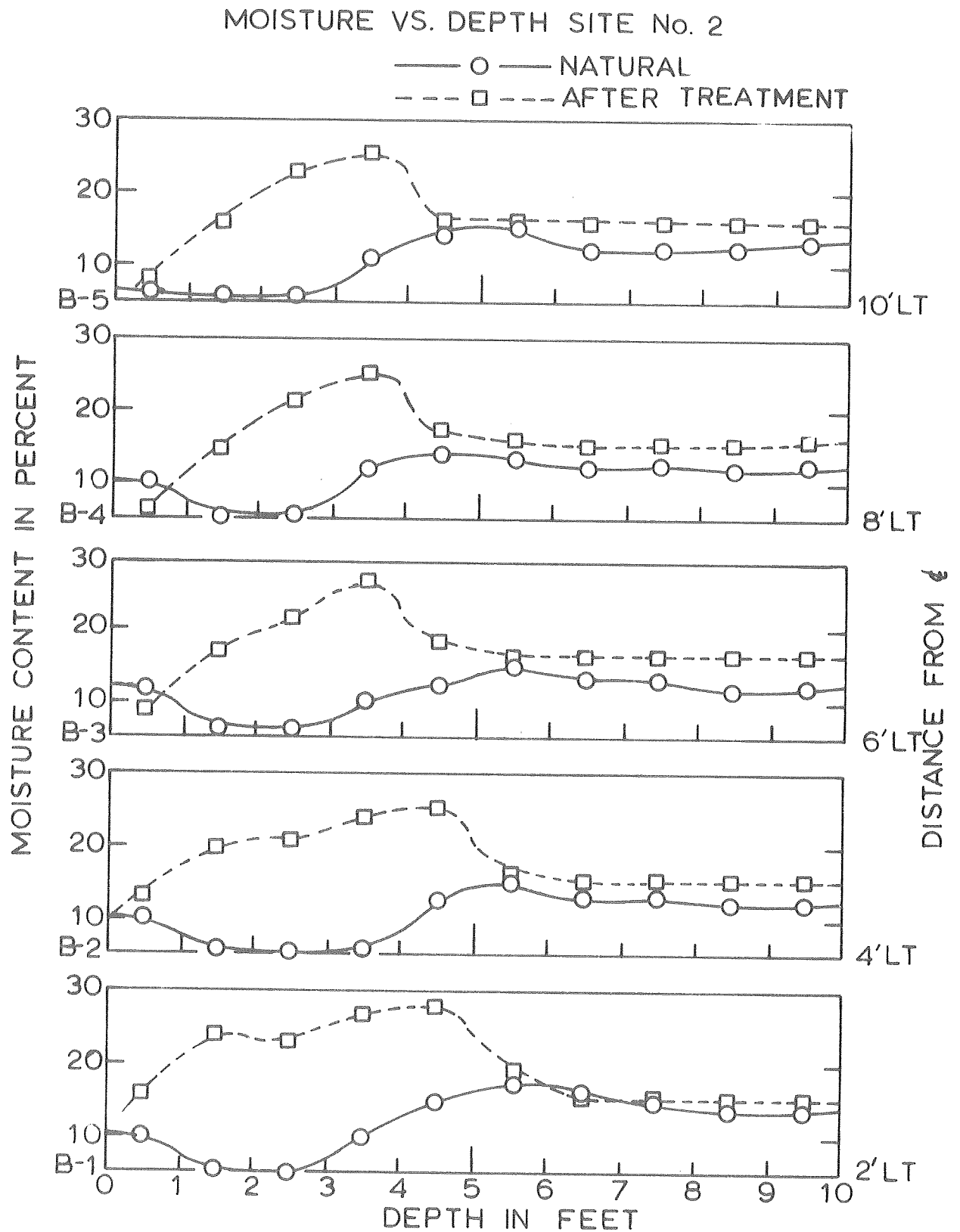


Figure 45

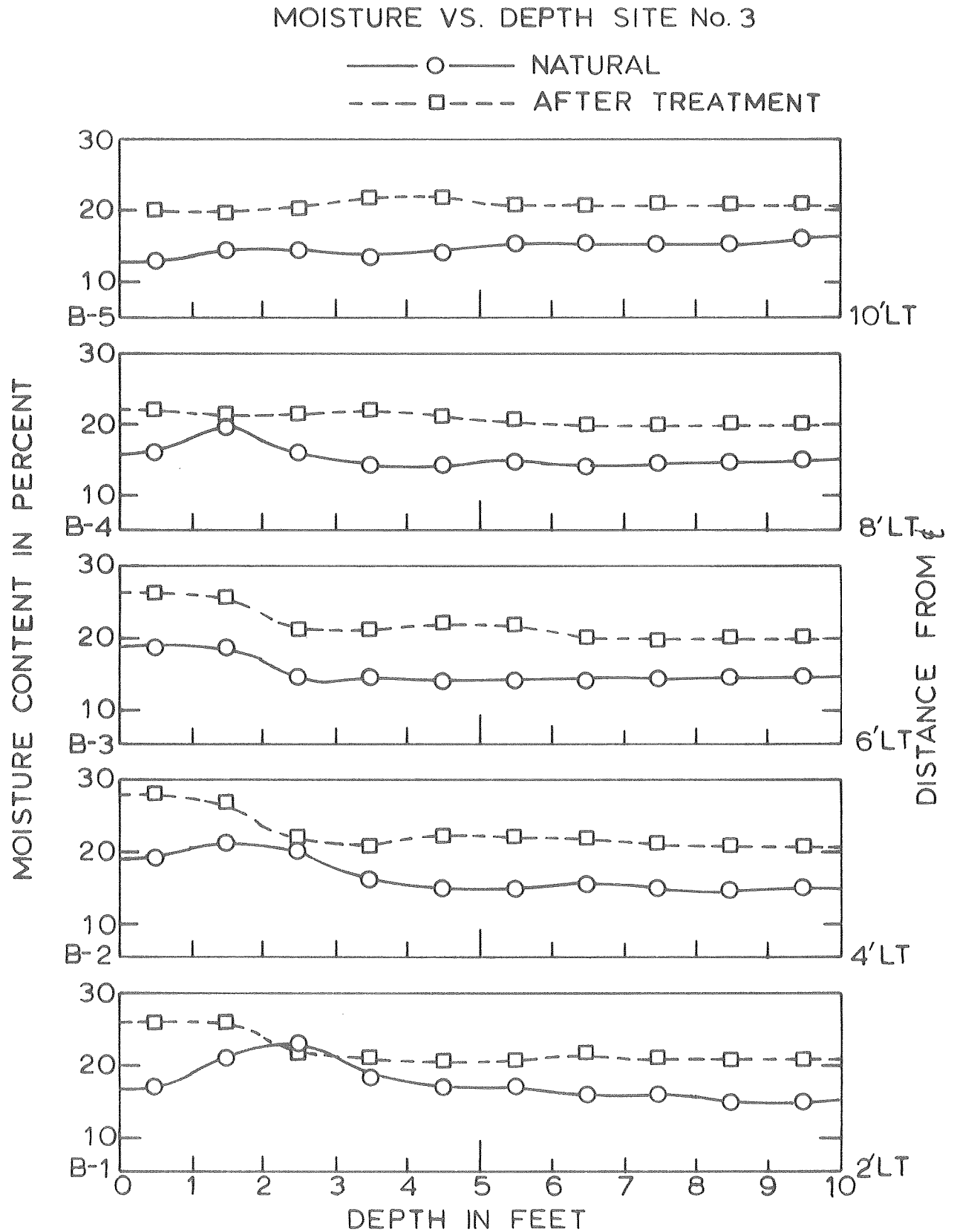


Figure 46

OPERATION

Treatment began at site one with application of solution on April 24. The solution was supplied twice a day to the solution wells being careful to keep the solution below the level of the base course. Solution was applied continuously in this manner until the completion of the test. Sites two and three were started May 1. As in site one, solution was added twice a day. In site two, the base course was flooded and site three only the trench was filled and care was taken to avoid getting solution in the base course.

Electro-osmotic treatment was started at 2 p.m. Monday, May 15. The voltage gradient for this test was based on past experience and was approximately 0.8 volts per inch. At 8 a.m. May 16 the western half of site 3 and all of site 2 were shut off because solution had reached the cathodes and the fuses on the control panel had blown. It was decided to discontinue adding solution and allow the sections to stabilize until 10 a.m. May 17.

In the interim it was decided to rewire the control panel. Using the existing wiring diagram it was possible to provide 30 amps to each circuit. This had proved to be more than sufficient based on past experiences; however, due to the change in the method of supplying chemical solution and the subsequent increase in the amount of solution readily available to the clay, the inplace resistance was decreased which caused a substantial increase in the amps in each circuit. It therefore became necessary for Mr. Rod McIntyre of the Arizona State University Engineering Development Shop to completely rewire the sites so they would carry 60 amps in each circuit. This was completed on

May 16, 1972 without further difficulties. In the future, it is recommended that heavier gauge wire be used in all field tests.

When the electro-osmotic treatment was resumed on May 17, no further problems were encountered. The test continued until May 19 when the current was shut off and the test completed.

The total solution consumed by the three sites can be seen in Table 6.

Table 6
SOLUTION CONSUMPTION

| <u>Site No.</u> | <u>Total Quantity of Solution (gallons)</u> |
|-----------------|---|
| 1 | 686 |
| 2 | 7,601 |
| 3 | <u>2,923</u> |
| Total | 11,210 |

SAMPLING

The Arizona Highway Department obtained both the moisture and expansive pressure samples using a rotary drill rig equipped with a four-inch flight auger. Sampling was started on May 22 with the drilling of the ten-foot-deep holes for moisture control samples. Ninety-four expansive pressure samples were taken at the locations indicated in Figures 41, 42, and 43. These samples were then transported to Arizona State University where the expansive pressure tests were run.

TESTING AND RESULTS

Moisture content samples were obtained and tested by the Arizona Highway Department. There were run on each one foot composite sample from the 15 ten-foot-deep holes. These results can be seen in the moisture

content versus depth plots, Figures 44, 45, and 46. All the expansive pressure tests were run on minus #4 material at a dry density of 100 pounds per cubic foot and a moisture content of 15 percent plus or minus 0.5 percent. (For the procedure see Appendix A.) The results of these tests can be seen in Tables 7, 8, and 9 and in Figures 47 and 48.

CONCLUSIONS

As a result of the testing, the recommended method is that of the solution wells. However, it is felt that the results for all three test sites would have been better if sufficient pre-sampling and testing had been undertaken. Because of incomplete data, the percent of KCl in the solution was far too low. The highest expansive pressure for the site based on pre-test sampling was 1800 pounds per square foot while post-test sampling indicated values as high as 12,000 pounds per square foot within two feet of the surface. This higher value would require much more KCl to stabilize it than the lower value.

Even though none of the sites received complete treatment, the advantages to the solution well method can be seen by comparing the results in Figures 44, 45, and 46 and Tables 7, 8, and 9.

The advantages in using the solution well method involve (1) greater uniformity of treatment, (2) greater depth of treatment, (3) less solution required, and (4) greater economy in treatment. All four of the advantages relate to the much greater horizontal than vertical permeability and to the fact that the solution wells are less affected by non-uniformity in the soil. Because of this, the use of solution wells over the other two arrangements is recommended.

Table 7
EXPANSIVE PRESSURES AND REDUCTION FACTORS
SITE NO. 1

| <u>Location</u> | <u>Depth in ft.</u> | <u>Expansive Pressure psf</u> | <u>Reduction Factor*</u> |
|-----------------|-------------------------|---------------------------------------|------------------------------|
| Untreated | 0-3 | 1100 | ---- |
| Untreated | 3-8 | 7500-15000 | ---- |
| A | 0-1 | 341 | 3.22 |
| A | 1-2 | 550 | 2.00 |
| A | 2-3 | 1017 | 1.08 |
| A | 3-4 | 5234 | ---- |
| A | 4-5 | 5596 | ---- |
| B | 0-1 | 451 | 2.44 |
| B | 1-2 | ---- | ---- |
| B | 2-3 | 407 | 2.70 |
| B | 3-4 | 791 | 1.33 |
| B | 4-5 | 12343 | ---- |
| C | 0-1 | 1095 | 1.01 |
| C | 1-2 | 253 | 4.35 |
| C | 2-3 | 747 | 1.47 |
| C | 3-4 | 11010 | ---- |
| C | 4-5 | 8847 | ---- |
| C | 5-6 | 11750 | ---- |
| D | 0-1 | 772 | 1.42 |
| D | 1-2 | 726 | 1.52 |
| D | 2-3 | 901 | 1.22 |
| D | 3-4 | 4990 | ---- |
| D | 4-5 | 12112 | ---- |
| D | 5-6 | 9222 | ---- |
| D | 6-7 | 4126 | ---- |
| D | 7-8 | 4011 | ---- |
| F | 1.5-2.5 | 199 | 5.53 |
| F | 2.5-3.5 | 385 | 2.86 |
| F | 3.5-4.5 | 7029 | ---- |
| F | 4.5-5.5 | 3828 | ---- |
| G | 0-1 | 635 | 1.73 |
| G | 1-2 | 264 | 4.17 |
| G | 2-3 | 421 | 2.61 |
| G | 3-4 | 7129 | ---- |
| G | 4-5 | 14942 | ---- |
| H | 0-1 | 594 | 1.85 |
| H | 1-2 | 758 | 1.45 |
| H | 2-3 | 268 | 4.10 |
| H | 3-4 | 734 | 1.50 |
| H | 4-5 | 3492 | ---- |

$$\text{Reduction Factor} = \frac{\text{Untreated Material @ } 100\#/ft^3 \text{ \& } 15\% \text{ H}_2\text{O}}{\text{Treated Material @ } 100\#/ft^3 \text{ \& } 15\% \text{ H}_2\text{O}}$$

Table 8
EXPANSIVE PRESSURES AND REDUCTION FACTORS
SITE NO. 2

| <u>Location</u> | <u>Depth in ft.</u> | <u>Expansive Pressure psf</u> | <u>Reduction Factor*</u> |
|-----------------|-------------------------|---------------------------------------|------------------------------|
| Untreated | 0-3 | 900 | ---- |
| Untreated | 3-8 | 7500-15000 | ---- |
| A | 0-1 | 243 | 3.71 |
| A | 1-2 | 1087 | 0.83 |
| A | 2-3 | 6915 | ---- |
| A | 3-4 | 9467 | ---- |
| A | 4-5 | 9293 | ---- |
| B | 0-1 | 232 | 3.88 |
| B | 1-2 | 130 | 6.92 |
| B | 2-3 | 275 | 3.27 |
| B | 3-4 | 2468 | ---- |
| B | 4-5 | 6273 | ---- |
| C | 0-1 | 375 | 2.40 |
| C | 1-2 | 1766 | ---- |
| C | 2-3 | 2500 | ---- |
| C | 3-4 | 9436 | ---- |
| C | 4-5 | 8886 | ---- |
| D | 0-1 | 1127 | ---- |
| D | 1-2 | 7515 | ---- |
| D | 2-3 | 6847 | ---- |
| D | 3-4 | 10536 | ---- |
| D | 4-5 | 14866 | ---- |
| E | 0-1 | 363 | 2.58 |
| E | 1-2 | 314 | 2.86 |
| E | 2-3 | 1296 | ---- |
| E | 3-4 | 4640 | ---- |
| E | 4-5 | 10720 | ---- |
| E | 5-6 | 15220 | ---- |
| E | 6-7 | 5267 | ---- |
| E | 7-8 | 4455 | ---- |

$$*\text{Reduction Factor} = \frac{\text{Untreated Material @ } 100\#/ft^3 \text{ \& } 15\% H_2O}{\text{Treated Material @ } 100\#/ft^3 \text{ \& } 15\% H_2O}$$

Table 9
EXPANSIVE PRESSURES
SITE NO. 3

| <u>Location</u> | <u>Depth in Feet</u> | <u>Expansive Pressure psf</u> |
|-----------------|--------------------------|---------------------------------------|
| A | 0-1 | 5081 |
| A | 1-2 | 12385 |
| A | 2-3 | 6079 |
| A | 3-4 | 4791 |
| A | 4-5 | 7603 |
| B | 0-1 | 7144 |
| B | 1-2 | 10765 |
| B | 2-3 | 7329 |
| B | 3-4 | 5344 |
| B | 4-5 | 5540 |
| C | 0-1 | 9480 |
| C | 1-2 | 5410 |
| C | 2-3 | 4669 |
| C | 3-4 | 5356 |
| C | 4-5 | 6074 |
| D | 0-1 | 3645 |
| D | 1-2 | 12299 |
| D | 2-3 | 5541 |
| D | 3-4 | 6533 |
| D | 4-5 | 6625 |
| E | 0-1 | 1330 |
| E | 1-2 | 10971 |
| E | 2-3 | 18925 |
| E | 3-4 | 9467 |
| E | 4-5 | 9249 |
| E | 5-6 | ---- |
| E | 6-7 | ---- |
| E | 7-8 | 6700 |

EXPANSIVE PRESSURE VS. DISTANCE FROM ANODE SITE No. ONE

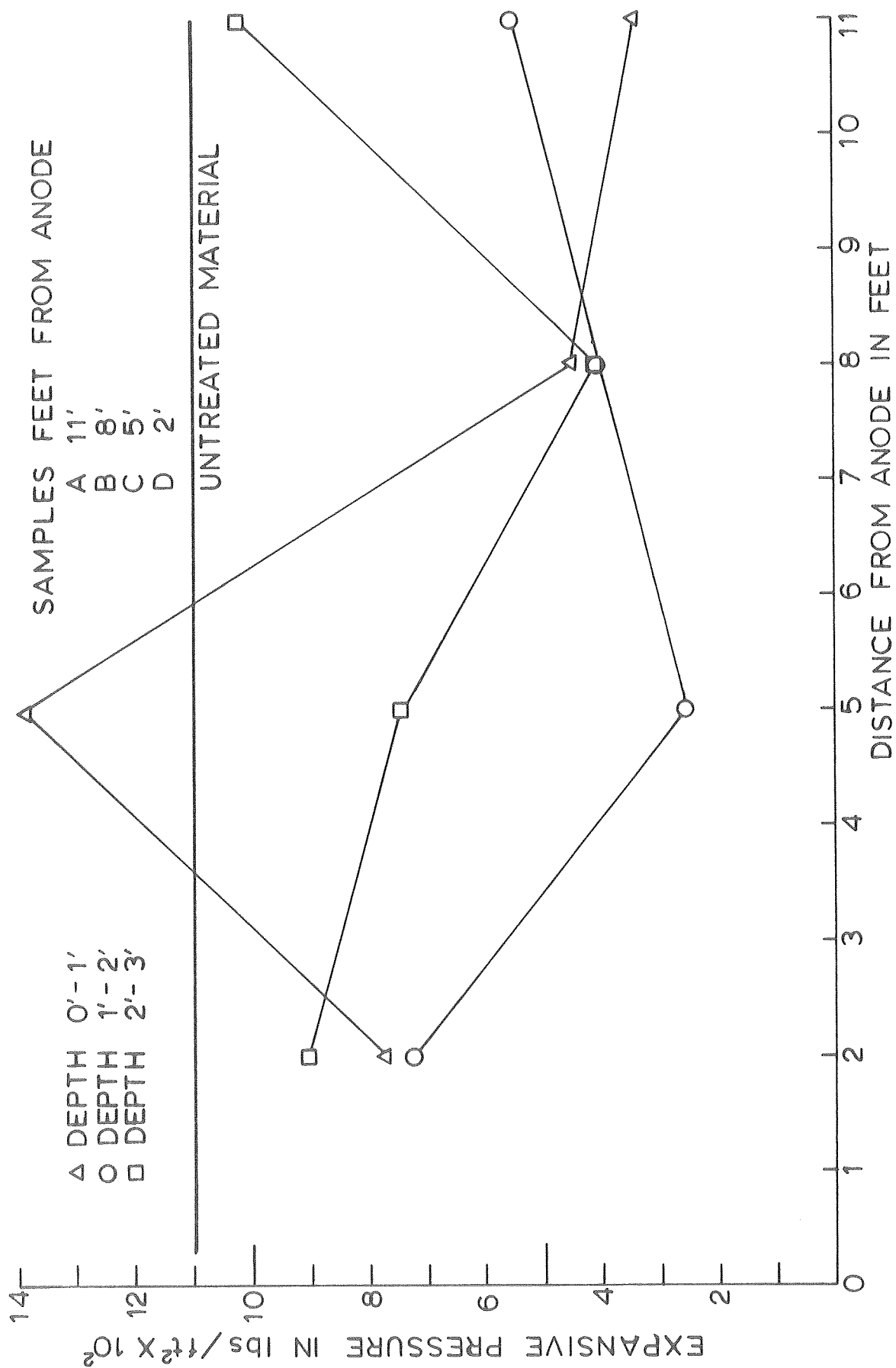


Figure 47

EXPANSIVE PRESSURE VS. DISTANCE FROM ANODE SITE No. TWO

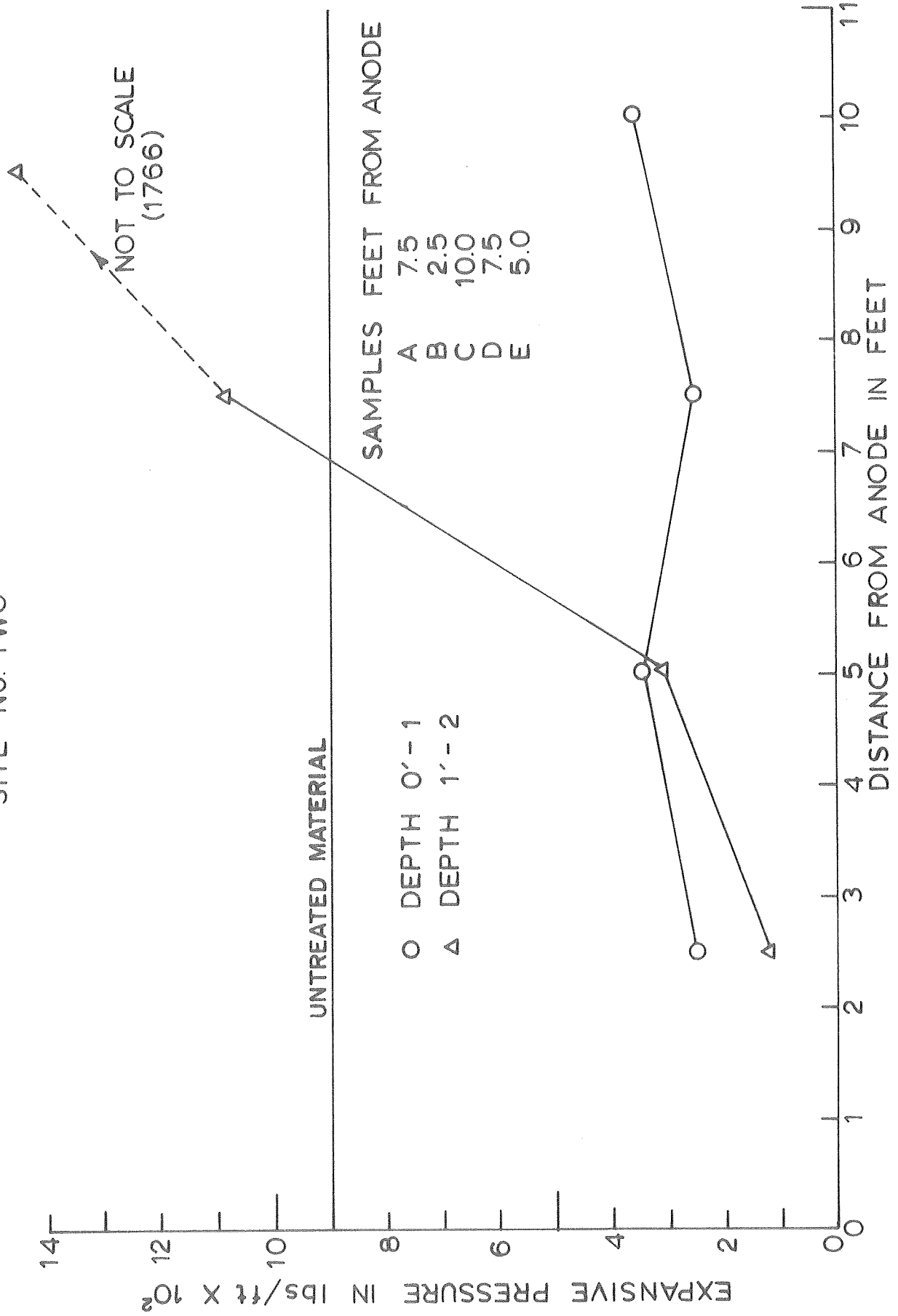


Figure 48

Chapter 7

SUMMARY OF RESULTS AND RECOMMENDED PROCEDURES FOR FUTURE TESTING

Summary

Over the period of the past year, extensive field and laboratory testing has been conducted on the Chinle Clay. Based on the results obtained, summarized below, it is recommended that the post hole method of stabilization be utilized in all future work.

The advantages of the post hole method are:

1. Greater uniformity of treatment,
2. Greater depth of treatment,
3. Less solution required, and
4. Greater economy in treatment.

In addition to the above reasons, another factor should be noted. The Arizona Highway Department took elevations on all three sites prior to treatment. The initial heaving caused by treatment was the lowest in the post hole section and amounted to only 0.15 of a foot. After treatment the area was subjected to heavy rains in the months of September and October, 1972, and elevations were again obtained. The results showed that there had been no further vertical movement in the post hole section. Based on this data, it appears that the post hole method would cause the least damage to existing pavement and that further heaving would be eliminated.

General

As a result of the laboratory and field testing, a tentative procedure for treating expansive clays has been developed. This procedure is dependent on several factors. The most important of these is that during treatment and for several weeks prior to treatment the average ambient temperature should be above 70 degrees. If temperatures fall much below this, problems will develop with regard to solubilities of the potassium chloride and the wetting agent C-61. A sufficient quantity of KCl depending on the expansive characteristics of the particular clay must be used to insure complete stabilization.

In any field stabilization program, it is important to consider the results of both expansive pressure and percent swell tests when planning to treat a section. If, for example, the expansive pressure is very high but the percent swell is low, the section might require less potassium chloride than a section with a lower expansive pressure but with a higher percent swell. For the suggested procedure for running these tests, see Appendix A.

The next process in the initial testing would be to determine the relative permeability of each of the composite samples. A rough but useful approximation of this is the time required to run an expansion pressure test. If the permeability of the site is fairly uniform with depth, it will be possible to treat the site as a single layered system. However, if widely varying permeabilities are noted, it may be necessary to treat each layer individually.

SUGGESTED PROCEDURE FOR TREATMENT OF EXPANSIVE CLAY

The following is the suggested procedure for treating a section of existing highway underlain by expansive soil.

Preliminary Exploration

Field work. Borings should be spaced a maximum of 20 feet on centers. If dipping beds or erratic soil conditions are present, closer spacing of the borings may be necessary. The borings should be advanced to a depth of 10 feet with composite samples taken every one foot.

Initial testing. Moisture contents should be taken for each composite sample and the results plotted versus depth. From this plot, an idea of the total depth necessary to treat the soil can be obtained. After the depth of treatment has been determined, expansive pressure and percent swell tests should be run. It is suggested that the tests be run on 2-foot composite samples from each boring or at each stratigraphic change. While this may be a large number of tests, if the proper technique is established they could be performed quickly and routinely, and therefore the problems encountered in the 1972 spring field test can be avoided.

The final step in the preliminary testing is to determine the amount of potassium chloride needed. For each range of expansive pressure noted, for example, 1000 psf - 1500 psf, 1500 psf - 2000 psf, various percentages of KCl by weight of soil versus expansive pressure curves should be plotted as was done in Chapter 3. From these curves, the optimum amount of potassium chloride needed can be determined.

Design of Section

From the results of the spring field test, it was determined that the solution well system used in site one (see Chapter 6) was the best method of treatment. In addition to the effectiveness, this arrangement caused the least damage to the existing pavement and thus, the least disruption of traffic. A third reason for using this arrangement is its adaptability to such factors as steep grades, non-homogeneous systems and depth of treatment.

Based on these results it is apparent that a five foot spacing of post holes will effectively reduce the expansive pressure of the clay, however, based on test hole A and on site inspections it appears that an eight foot spacing of post holes will be as effective. This increase in spacing would mean fewer holes and, therefore, greater economy in treatment. This distance would not be excessive as the results from Phase IV indicated that the solution could be moved as much as 19 feet in a horizontal direction.

Installation

The solution wells should be bored to within one foot of the maximum depth of soil to be treated. This is suggested because in model studies (see Chapter 5) and in the spring field test (see Chapter 6), the horizontal permeability is much greater than the vertical permeability. This is caused by both stratification of the natural soil and by the effects of electro-osmotic gradient. In a very permeable soil, the

solution wells would not need to be this deep. The wells then should be filled with clean gravel to prevent caving of the sides. This is particularly important if traffic will be using the lane during treatment.

The electrodes can be either horizontal or closely spaced vertical rebar. The effectiveness of the vertical rebar would depend on the spacing. The anodes should be the equivalent of No. 8 rebar while the cathodes should be No. 4 bars. The larger size for the anode is necessary because metal is removed from the positive electrodes during the electro-osmosis process. If vertical electrodes are used, they should be driven the entire depth of the section to be treated. Horizontal electrodes should be placed approximately at a depth of one-half of the total thickness of the section to be treated. If horizontal electrodes are used, moist soil should be compacted around the electrodes before back-filling the trenches.

Operation

After the installation is completed, the treatment is begun by filling the post holes with the potassium chloride solution, being careful to keep the level of the solution below the base course. This is important because allowing solution to enter the much more permeable base course will prevent thorough treatment of the less permeable clay. The solution should contain 20-30 percent of potassium chloride to reduce the expansive pressure to an allowable limit and approximately 0.5 to 1.0 percent of the wetting agent C-61.

Filling of the solution wells should be continued daily until the completion of the treatment.

Electro-osmosis should be started either when the solution wells stop taking solution or when the solution reaches the cathodes. The suggested voltage gradient is between 0.6 to 1.0 volts per inch. The reason electro-osmosis should continue after solution has reached the cathode can be seen in the model studies, Chapter 5. Because the K^+ is removed from solution by the clay, the solution reaching the cathode may contain little potassium. The electro-osmosis will continue to pull solution across the section under treatment, thus providing additional K^+ ions to the clay. An additional benefit of the continued electro-osmosis is that it will increase the uniformity of the treatment.

The electro-osmosis should be continued until the section is stabilized. This point can be determined by one or both of two methods. The first involves chemical analysis of the clay near the cathode. When the potassium content reaches that of a predetermined desirable level, treatment can be stopped. The second, probably easier to run and more informative, is to measure the expansive pressures of several samples taken near the cathode.

CONCLUSIONS AND RECOMMENDATIONS

The main conclusion of this study is that the post hole method of electro-osmotic stabilization of an expansive clay can be employed with satisfactory results provided certain precautions are followed.

Since this procedure was developed as the result of small-scale field and laboratory testing and the technique has never been employed in a large-scale field test, it is recommended that the Arizona Highway Department undertake a large-scale field test at its earliest convenience. As a result of this test the existing procedure may be modified for further programs. It should be noted that the procedure as given is of necessity general and that the various parameters must be determined for each particular job.